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Human Health and the Indoor Environment: An Analysis of Building Materials and Sustainable Architecture

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Human Health and the Indoor Environment: An Analysis of Building Materials and Sustainable Architecture

by

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Thesis

Presented to the Faculty of the Graduate School of

The University of Texas at Austin

in Partial Fulfillment

of the Requirements

for the Degree of

Master of Science in Sustainable Design

The University of Texas at Austin

December 2019

Abstract

Human Health and the Indoor Environment: An Analysis of Building Materials and Sustainable Architecture

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The University of Texas at Austin, 2019

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In our modern industrial world, humans have migrated from the outdoors to indoor environments. Americans on average spend 93% of their time indoors and indoor air quality is a top threat to human health according to the U.S. Environmental Protection Agency. While energy reduction is often the most well-known aspect of sustainable design, human health is also significant because of our indoor lifestyles. One aspect of sustainable design is the selection of building materials that are safe for both humans and the environment. The lifecycle of a building product is important, but the lifecycle of humans should also be a design priority. This thesis explores the relationship between indoor environmental quality and building materials and aims to address points in architecture that are beneficial for human health and the indoor environment. Since the indoor environment is influenced by a variety of factors, there are many areas for opportunity. While healthy homes do exist, most homes in America are made using materials that may pose risks to human health. This thesis addresses which methods of

sustainability are most appropriate to meet the current demands of new construction. As humans continue to spend more time indoors, the importance of materials decision is amplified. Designers and architects have the ability to choose materials that can protect human health indoors.

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Chapter 1: Introduction

"Reality is indoors, what matters and is familiar and under control is indoors"

- Kim Stanley Robinson, *New York 2140*, 2017

Human Health and Sustainability

Sustainable architecture responds to the needs of both humans and the environment. There are various competing logics of sustainable architecture and each designer must make decisions to find a balance between the competing logics. New building materials may offer high performance and economic incentives but could pose risks for human health and the environment. Toxic and unhealthy buildings are poor expressions of architecture. Sustainable architecture at a minimum causes no harm to humans and the environment while having the potential to go beyond the minimum of avoiding harm by promoting wellbeing. A building cannot truly be sustainable if one sustainable logic is compromised for another logic.

Sustainable architecture does not have one exact meaning but is generally linked to broader ideas of sustainability. The term sustainability was first used in 18th German forestry. The idea was simple: if you cut down a tree, you plant a new one. The term was later coined by Norwegian politician Gro Harlem Brundtland in 1987 at the World Council on Economic Development. Brundtland stated that sustainable development must "meet the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987, pg. 15). While she wrote about sustainability in the context of development, her concept of sustainability can be applied to all aspects of building. About a decade later in 1996, Scott Campbell, an urban planning professional and professor, wrote that sustainable development must meet environmental, economic and social needs. While sustainable design does aim to meet those goals, there are other aspects of sustainability missing in Brundtland and Campbell's statement.

Simon Guy and Graham Farmer, both planners and architects, defined six competing logics of sustainable architecture: eco-technic, eco-centric, eco-aesthetic, eco-cultural, eco-medical, and eco-social. The eco-medical logic focuses on the interior of a building and advocates for the "sustaining of individual health" (Guy and Farmer, 2013, pg. 145). Indoor air quality is a key aspect of sustainability. "In the case of buildings, the eco-medical logic tends to focus a critical attention on the interior of buildings, where the concept of sick building syndrome is a familiar emblematic issue applied to both working and domestic environments" (Campbell, 1996, pg. 145). Indoor air quality is impacted by many factors including material selection. Certain materials can promote healthy indoor air quality while reducing the total embodied energy of a building while other materials pose risks to human health and are harmful to the environment. Competing ideologies of sustainability have been present since the term was first used and some of the first initiatives behind green building were to reduce energy exposure. For example, during the 1970s, air exchange rates were decreased to reduce energy, but this led to poor indoor environmental quality (Allen, 2016). One sustainable initiative should not compromise another sustainable initiative. It is important to note that human health depends on both the decisions made by design professionals and the occupant's behavior throughout the life of the building.

Climate Change Critique

In *Beyond the Climate Crisis: A Critique of Climate Change Discourse,* Eileen Crist argues that a sustainable future will require a change in lifestyles. She also argues that climate change discourse receives most of the attention in the environmental movement. She states,

> "Climate change looms so huge on the environment and political agenda that is has contributed to downplaying other facets of the ecological crisis: mass extinction of species, the devastation of oceans by industrial species, continued old-growth forest deforestation, topsoil losses and desertification, endocrine disruption, incessant development, and so on, and made to appear secondary and more forgiving" (Crist, 2007, pg. 35-36).

Because of this pattern, the term sustainability is often seen as solely energy reduction without awareness of other environmental facets. Human health goals do not always align with energy reduction goals. The two are often in competition with each other and human health has been compromised in order to meet energy reduction goals. Indoor air scientist Dr. Jeffrey Siegal states, "of course we should care about energy, but at the same time we should be thinking about people's health inside of buildings" (Siegal, 2013). Siegal suggests strategies that address both the indoor environment and energy efficiency. He discusses the challenges of indoor air quality and states that some of the challenges stem from the fact that indoor air science is overall a new field of research and instrumentation is changing the way we measure and assess the indoor environment.

“There are many green building programs that seem to address IAQ, LEED being one of them for example. The problem is that indoor air quality as a science is very much in its infancy so a lot of things that we think are doing for indoor air don’t actually address indoor air that well” (Siegal, 2013). Siegal mentions that semi-volatile organic compounds (SVOC) were not on the radar a decade ago but now they are recognized as an important factor of human health indoors. New instrumentation is helping scientists measure smaller particles which impact indoor air and environment, but it is still difficult to determine which strategies are most significant and impactful for human health.

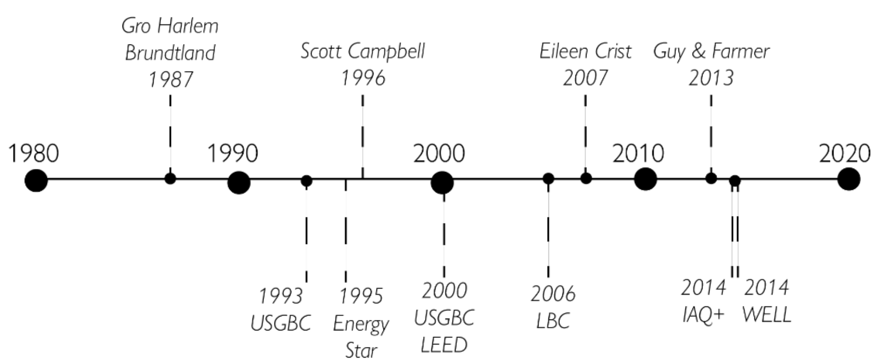
In figure 1.1 below, the different facets of modern sustainability are shown along with green building certifications for reference. Brundtland’s statement is about time and longevity and Campbell’s statement is about finding a balance between economic, social, and environmental values. Crist’s statement is about the political complexity of sustainability while Guy and Farmer wrote about system comprehensiveness and the multi-faceted approach of sustainable architecture. The figure below also shows that sustainable architect is a relatively new field.

SUSTAINABLE ARCHITECTURE EVOLUTION

Gro Harlem Brundtland 1987	**Time and Longetivity**	*Sustainable development must "meet the needs of the present without compromising the ability of future generations to meet their own needs"*
Scott Campbell 1996	**Balance**	*Planner's Triangle: Economic, Environmental, & Social*
Eileen Crist 2007	**Political Complexity**	*"Climate change looms so huge on the environment and political agenda that is has contributed to downplaying other facets of the ecological crisis"*
Guy & Farmer 2013	**System Comprehensiveness**	*Competing logics of sustainable architecture: Eco-technic, Eco-centric, Eco-aesthetic, Eco-cultural, Eco-medical, and Eco-social.*

The ideas and definitions of sustainability have evolved over time and sustainable architecture is more than just energy efficiency and includes ideas about social equity and human health.

EVOLUTION OF SUSTAINABLE ARCHITECTURE + GREEN BUILDING CERTIFICATIONS



The evolution of sustaianable archtiecture and the first green building certifications happend around the same time.

Figure 1.1: Green Building Certifications and Evolution of Sustainable Architecture

Significance and Importance

Indoor air is important because it is directly related to human health. "The United States Environmental Protection Agency (EPA) and its Science Advisory Board (SAB) have ranked indoor air pollution among the top environmental risks to public health" (U.S. EPA, 1987a; U.S. EPA-SAB, 1990). Because air is invisible and particles are impossible to detect with the human eye, the threat of poor air is often undermined. Energy savings can be calculated in kilowatts and dollars, but it is difficult to estimate healthcare costs and even more challenging to assign a monetary value to quality of life.

Architecture is both protecting and hurting us at the same time. One of the reasons the risk of poor indoor air is so high is because the amount of time we spend indoors. Humans have gradually transitioned from being an outdoor species to an indoor species. The National Human Activity Pattern Survey (NHAPS) shows where humans spend their time. The data from this study was collected between 1992-1994 and the study was sponsored by the EPA. According to the NHAPS, participants spent about 87% of their time indoors (Klepeis et al, 2001, pg 15). We may spend even more time indoors now than we did in the early 1990s. text

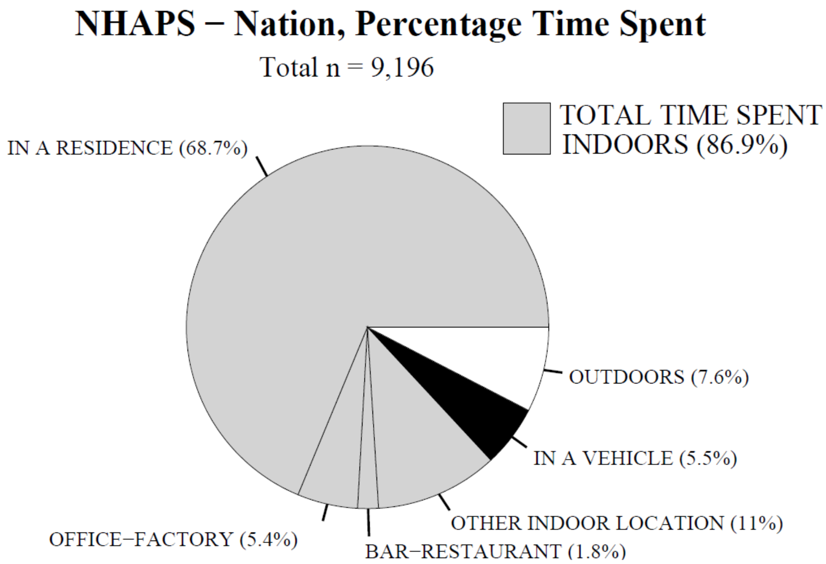


Figure 1.2: National Human Activities Pattern Survey
Source: Klepeis et al, 2001, pg. 15

According to the NHAPS, more time is spent in a residence than any other place. Because of the amount of time humans spend in a residence, this thesis will focus on residential architecture in the United States. The home is an important space because in addition to being a place of protection and respite, "more than half the body's intake during a lifetime is air inhaled in the home. Thus, most illnesses related to environmental exposures stem from indoor air exposure" (Sundell, 2004, pg. 51). Some of the challenges of this thesis deal with the lack of research on residential architecture. "Studies on the association between health effects and ventilation rates in homes are rare" (Sundell, 2004, pg. 55). While they exist for commercial environment, the home is not studied as frequently. It is also difficult to establish either correlation or causation because it is unethical to test a potentially harmful substance on humans.

The indoor environment is extremely important because we spend a majority of our time indoors. Dr. Jeffrey Siegel wrote an article called *Engineering the Indoor Environment*. Siegel states, “The average person breathes, by comparison, approximately ten times more indoor air than they consume in water (in both food and drink)” (Siegel, 2011, pg. 349). If we care about standards for food and water, then we should certainly pay attention to indoor air. Outdoor air, food, and water are heavily regulated, but there are no national regulations for indoor air. Outdoor air does play a role in indoor air because the air that enters the indoor comes from the outdoors. The significance of this thesis is underscored by the fact that we spend a majority of our lives indoors and this environment is the only place of exposure for some of these toxins. Unhealthy indoor environments affect all people, but not equally. People who live in low-income areas are more likely to experience poor indoor air quality. “Indoor concentrations of multiple pollutants are elevated in low-socioeconomic status households” (Adamkeiwicz, 2011, pg. S238). Children, elderly, and people who have sickness or compromised immune systems are more likely to spend time indoors and can be impacted by the indoor environment more than a healthy middle-aged person. Because there is little to no regulation for the indoor environment, it is the designer’s responsibility to choose materials that promote indoor environmental quality.

Research Methods

Research methods consist of literature reviews, historical research, and case studies. The different methods of research will provide a cross research approach. Both quantitative and qualitative data was collected and presented throughout the paper in graphs and charts. Literature reviews were based on relevant and recent scientific peer-reviewed articles. Most article related to indoor air and environmental quality, human health, and toxicity indoors. Data from the EPA and CDC was used throughout the paper. Historical research was implemented by looking at evidence and historical analysis gives understanding of current conditions. Historical events and government regulations impact current indoor air quality. Case studies provide examples of residential buildings and analyze the characteristics of common materials. Some case studies show examples of healthy indoor environments while others show examples of unhealthy environments. Different research methods allowed for both historical analysis and understanding of current conditions.

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Chapter 2: Importance and Relevance of the Indoor Environment

"The outdoors is what you must pass through in order to get from your apartment into a taxicab" - Fran Lebowitz, *Metropolitan Life*, 1978

Architecture as Protection and Threat

Food, water, and shelter are the most basic human needs. Throughout history, architecture has provided shelter and safety. While contemporary architecture does `protect humans from the outdoor elements, our shelter is also causing harm by posing risks to human health. The indoor environment is the only place of exposure for certain harmful chemicals and indoor air pollution is a top risk to human health. The indoor environment, which primary served to protect us, is now one of the top threats to our health. Our homes have the ability to promote human health and wellbeing or to jeopardize human health and wellbeing.

Sick building syndrome (SBS) is a term coined in the 1980s used to describe acute symptoms from the indoor environment where occupants feel sick and uncomfortable. Usually symptoms go away when the occupant leaves the building. Building related illness (BRI) is related to SBS but refers to specific symptoms such as headache and sneezing. “The effects of BRI (asthma, legionellosis, fiberglass dermatosis, etc…) are caused by airborne contaminants. The cause of SBS are more ambiguous” (Guzowski, 1999, pg. 307). Because modern work environments keep us tethered to desks with computers, many building occupants are not able to leave the building if they feel uncomfortable. While everyone is affected by the indoor environment, individuals with multiple chemical sensitivity (MCS) may experience worse symptoms. Multiple chemical sensitivity is a condition where someone experiences discomfort from the low-level exposure of multiple chemicals. The synergistic effects of combined chemicals is unknown. Chemical contamination indoors can lead to occupants being unproductive and uncomfortable. “Human comfort is based on the quality of the following primary environmental factors: temperature, humidity, air movement, temperature radiation to and from surrounding surfaces, air quality, sound, vibration and light.” (Ballast, 2010, pg. 25-8). It is important to design for both human health and comfort.

Indoor Environmental Quality (IEQ) and Indoor Air Quality (IAQ)

The indoor environment is influenced by a variety of factors including outdoor air, indoor building materials, human activities, and the home’s heating, ventilating, and air conditioning (HVAC) system. The HVAC systems exchanges old stale air with fresh filtered outdoor air. While there are numerous calculations on the perfect air exchange rates, generally the higher rate the better for the health of indoor occupants. Because outdoor air quality is a factor of indoor air quality, indoor air quality will vary by region. Modern humans are an indoor species and their primary environment is the indoor environment. Indoor environmental quality (IEQ) is a term used to describe all the factors of the indoor environment including but not limited to: indoor air quality (IAQ), lighting, noise, views, and comfort. “A variety of factors influence the health of building, including ventilation, building materials, temperature, humidity, moisture control, and lighting conditions. The primary culprit, however, is believed to be poor IAQ" (Guzowski, 1999, pg. 307). While each factor of IEQ is important, IAQ is significant because many of the most concerning chemicals are airborne. IEQ is a newer term used more frequently and even though this term describes more than IAQ, it is often a replacement for IAQ. Figure 2.1 shows the relationship between IAQ and IEQ.

INDOOR AIR QUALITY AND
INDOOR ENVIRONMENTAL QUALITY

IAQ	IEQ
Outdoor Air	IAQ
Temperature	Lighting
Humidity	Views
Particles	Noise
Contamination	

Indoor environmental quality is a newer term that is often used as a replacement for indoor air quality.

Figure 2.1: IAQ and IEQ

Contamination

Contamination affects both IEQ and IAQ directly because many contaminants are airborne. One of the reasons why indoor air is more contaminated than outdoor air is the variety of contamination sources. Pollutants can be categorized in two ways: biological or chemical. Common biological pollutants are dust, mold, asbestos, arsenic, radon, lead, and bacteria. Common synthetic contaminants are VOCs, SVOCs, PBDEs, other flame retardants, solvents, pesticides, synthetic formaldehyde, benzene, phthalates, and plastics. Many of these chemicals come from building products. Pollutants, if controlled, are not a problem. "The exposures are the result of complex interactions between the structure, building systems, furnishings, the outdoor environment, and the building occupants and their activities. As people spend more time indoors, the opportunities increase for significant health effects resulting from these exposures" (Mitchell, 2007). It is difficult to establish causation between a building materials and human health because there are so many variables to calculate. The building envelope and ventilation play a role in the indoor environment by carrying away pollutants. "Ventilation is required to provide oxygen and remove carbon dioxide, to remove odors, and to carry away contaminants" (Ballast, 25-11). While proper ventilation is crucial for a healthy indoor environment, reducing contamination is also necessary. Indoor sources of contamination can come from combustion (cooking, fireplaces, indoor smoking, burning candles), cleaning supplies (VOCs), and building materials (degrading and new).

Dr. Jeffrey Siegal recommends reducing exposure to contamination. There are many opportunities to reduce exposure. He states,

> "The most common contaminant of indoor air includes the volatile organic compounds (VOC). The main sources of VOC are adhesives, upholstery, carpeting, copy machines, manufactured wood products, pesticides, cleaning agents, etc. Environmental tobacco smoke, respirable particulate matter, combustion byproducts from stove, fireplace and unvented space heater also increase the chemical contamination. Synthetic fragrances in personal care products or in cleaning and maintenance products also contribute to the contamination" (Siegal, 2011, pg. 349).

Volatile organic compounds (VOCs) are known neurotoxins, toxins that destroy nerve tissues. VOCs are one class of chemicals indoors and they are significant factor of both SBS and BRI. While there are numerous sources of chemical contamination, this thesis will focus on the contamination from architectural elements, specifically interior elements. It is nearly impossible to calculate the synergistic effects of all the chemicals in an indoor space. “The combination of these chemical sources in buildings can result in the occupant being exposed to anywhere from 50 to 300 different individual VOCs, each present in a microgram per cubic meter concentration range (mg/m3)” (Bernstein, 2008, pg. 587). The sum of all VOCs is referred to as Total VOCs (TVOCs). The synergistic effects of these chemicals are unknown and there are no safe levels set for many common contaminants. VOCs are not the only chemicals of concern. “Primary product sources of VOCs in buildings include office furniture, cabinetry, carpet tile, vinyl wall coverings, paints, and adhesives. Primary formaldehyde emitters are paints, adhesives, insulations, cabinetry, workstations, ceiling tile, and wallboard” (Allen, 2016, pg. 587). Another chemical that is known to cause health risks to humans is formaldehyde which is used as a resin to bind materials together. While formaldehyde does work well for this purpose, the benefits of performance do not outweigh the risks of cancer. Phthalates are another chemical of concern because they can disrupt the endocrine system, which is made of hormones that regulate many bodily functions. Phthalates are found in a variety of products including vinyl flooring. When phthalates, formaldehyde, and VOCs interact, the effects are unknown.

We are being exposed to a variety of chemicals in the indoor environment. Some of these are suspected to be harmful, but evidence is difficult to find. “Many conferences have been held and many papers written on the possible association of air pollution with disease. As might be expected, firm evidence of harmfulness is difficult to explain”

(Wolmam, 1965, pg. 188). While this quote is from 1965 and there is more data available, it is still difficult to draw conclusions. Evidence is difficult to find because it would be unethical to test a chemical on a human if that chemical is suspected to be harmful. Even if a material is proven to be harmful, it can still be used in building materials and chemical manufactures are not required to list all ingredients in a building product. “The evidence is strong regarding an association between IAQ and lung cancer, allergies, other hypersensitivity reactions (including sick building syndrome (SBS), and multiple chemical sensitivity (MCS), and respiratory infections” (Sundrell, 2004, pg. 54). Given the strong evidence, it is crucial that building products that cause poor IAQ should be avoided.

Inconclusive Data

It is difficult to establish causality between a human health symptom and a building material. “In general, scientific studies have not shown an association between health effects and commonly measured agents such as VOC, TVOC, particulate matter, and microbially produced matter” (Sundell, 2004, pg. 55). Sundell states that there are many problems with current indoor air research because the techniques used indoors are the same used for other environments and the methods aren’t suitable. Sundell suggests more appropriate and suitable research. However, the EPA states that the health effects of VOCs include “eye, nose and throat irritations, headaches, loss of coordination and nausea, damage to liver, kidney, and central nervous system, and some organics are suspected or known to cause cancer in humans" (U.S. EPA, 2017). While the data and health effects are inconclusive, there is data regarding cognition and performance that is more conclusive.

Air and Cognition

Outdoor air pollution has a direct impact on cognition. "Long-term exposure to air pollution impedes cognitive performance in verbal and math tests" (Zhang et. al, 2018, pg. 9193). There are also social issues with air pollution. "Polluted air may impede cognitive ability as people become older, especially for less educated men" (Zhang et al, 2018, pg. 9193). As a growing number of Americans reach retirement, this could become a medical and economic problem. People who work in indoor spaces that are well ventilated and with below average level of chemical contaminants are more productive than people who work in standard indoor work environments. "Workers in green certified buildings scored 26.4% higher on cognitive function tests, controlling for annual earnings, job category and level of schooling, and had 30% fewer sick building symptoms than those in non-certified buildings" (MacNaughton, 2017, pg. 178). In addition to performing better at work, building occupants in green buildings felt more comfortable in their work environments.

Another group of researchers found similar results. A study from Harvard's Chan School of Public Health, SUNY Upstate Medical University, and Syracuse University revealed that, "on average, cognitive scores were 61% higher on the green building day and 101% higher on the two green+ building days than on the conventional building day ($p < 0.0001$). VOCs and CO2 were independently associated with cognitive scores" (Allen, 2016). While it is extremely difficult to establish causation regarding human health and risks to certain diseases, this study was able to prove that people are more productive and have higher cognition in "green" work environments. This study further confirms the importance of the indoor environment. While there are no similar studies done in residential architecture, it is reasonable to assume that productivity in "green" homes would be higher than in conventional homes.

Financial Impact from Lost Productivity

In *Our Common Future*, Brundtland stated, "yet many industrialized and most developing countries carry huge economic burdens from inherited problems such as air and water pollution, depletion of groundwater, and the proliferation of toxic chemicals and hazardous waste" (Brundtland, 1987, pg. 26). Health problems are linked to economic problems. "The EPA estimates that as many as 21 million Americans may be affected [by poor IAQ] resulting in lost productivity, medical problems, and damage to materials and equipment costing tens of billions of dollars per year" (Guzowski, 1999, pg. 307). Healthy building products may cost more money upfront, but they may save building occupants from future medical bills. Poor IAQ disproportionally affects the most vulnerable including children and the elderly. "The damage on the aging brain by air pollution likely imposes substantial health and economic costs, considering that cognitive function is critical for the elderly for both running daily errands and making high-stake decisions" (Zhang et al, 2018, pg. 9193). It is difficult to calculate and assign monetary values to cognition, but researchers have stated that poor air quality will cost Americans billions of dollars at the least and can also jeopardize quality of life.

Time Spent Indoors

Indoor air is a threat to human health partly because of the amount of time we spend indoors. At some point in history, humans spent all their time outdoors. Refuge was found in caves and eventually in tents, but for the most part humans lived and worked outdoors. After both the agricultural and industrial revolution, many Americans left the farms for the factories in the cities. We now spend over 90% of our time indoors. Chronic low-level exposure is a term used to describe the health impacts of indoor air. "Because Americans spend approximately 22 hours every day indoors, susceptible individuals are at much greater risk of adverse health effects from chronic low levels of exposure to indoor air pollutants over time" (Bernstein, 2008, pg. 585). Children, elderly, and people with sickness often spend more time indoor than healthy middle-aged people and are at a higher risk for exposure. Children today spend about half as much time playing outdoor than their parents. While we cannot predict the future, it is reasonable to assume that humans will continue to spend a significant portion of their time indoors. The fact that we are an indoor species is undeniable, but how much time we spend outdoors varies between people. Our modern work environments and technology keep us tethered to our desks with stationary equipment and while many people wish to spend more time outdoors, the indoor environment may be the only option. Post industrial revolution work was inside in factories rather than outside at the farm. Today about half the world lives in cities and people continue to move to cities. "By 2030, it is expected that nearly 5 billion (61%) of the world's 8.1 billion people will live in cities" (United Nations, 2018). This percentage will continue to rise as more people continue to move to cities. People who live in cities spend more time indoors than people who live in suburban and rural environments.

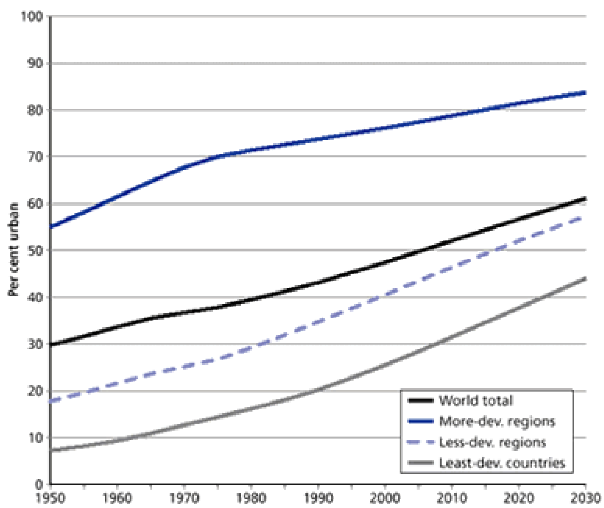


Figure 2.2: World Urbanization Prospects
Source: United Nations

Agency of the Indoor Environment

Indoor environmental quality is dependent on the decisions made by a variety of professionals including but not limited to: the owner or developer, mechanical engineer (on large projects, but usually not for single residential home), civil engineer / landscape architect, general contractor, architect, interior designer, and the building occupants. Figure 2.3 shows the different decisions that each professional makes that impact the indoor environment. Typically, the developer or owner would work together with the builder and architect to specify building materials. Depending on the type of project, the roles vary. A custom home would most likely have an architect and interior designer involved while a production home may not have either professional consultant involved in the building process. The civil engineer plays an important role because proper drainage reduces risk of mold. The landscape architect will design the outdoor spaces which will influence how much dirt/debris will enter the home.

Interior designers play a significant role regarding IEQ because they usually design and specify all the interior surfaces which occupants come into contact with daily. "Although architects and engineers are primary responsible for the design and remodeling of most HVAC systems, interior designers should be aware of the systems and their functioning since these systems have a direct influence on the quality of the interior environment and affect the aesthetic considerations of the space" (Kilmer, 2016, pg. 375). While typically engineering and interior design are seen as separate professions, it is important that the interior designer has awareness of IEQ because of the impact that materials can make on the indoor environment. The occupant plays an important role because their behaviors influence their health. Improper cooking techniques can cause poor IEQ and toxic cleaning products will lead to chemical contamination. Keeping the house dust free can improve IEQ. While there are many behavioral strategies that address occupant health, this thesis will focus on methods at the level of the built environment.

INDOOR ENVIRONMENTAL AGENCY

OWNER / DEVELOPER
-Primary stakeholder
-Primary decision maker
-Material selection

LANDSCAPE ARCHITECT / CIVIL ENGINEER
-Tracking of dirt / debris in home
-Mold / drainage

GENERAL CONTRACTOR
-Material selection
-Sourcing materials

ARCHITECT
-HVAC
-Insulation
-SubFloor
-Walls
-Windows

INTERIOR DESIGNER
-Interior Paint
-Flooring
-Lighting
-Cabinets
-Furniture Selection
-Range and hood selection

OCCUPANT
-Cleaning
-Cooking
-Smoking
-Track dirt and debris
-Open windows and doors
-Electronics
-New Products
-Pets

A variety of individuals and groups of people from different professional backgrounds make the choices that impact indoor environmental quality.

Figure 2.3: Indoor Environmental Agency Chart

Chapter 3: History, Competition, and Regulation of Indoor Air

"Clean air, clean water, open spaces – these should once again be the birthright of every American. If we act now, they can be. We still think of air as free. But clean air is not free, and neither is clean water. The price tag on pollution control is high. Through our years of past carelessness, we incurred a debt to nature, and now that debt is being called."

– Richard Nixon, *State of the Union*, 1970

History of Indoor Air and Environment

The quality of the indoor environment has been considered for thousands of years. Ancient homes were subject to a variety of natural contaminants like dust, pollen, and mold and the Bible describes a house with mold as unclean. "If the defiling mold reappears in the house after the stones have been torn out and the house scraped and plastered, the priest is to go and examine it and, if the mold has spread in the house, it is a persistent defiling mold; the house is unclean. It must be torn down—its stones, timbers and all the plaster—and taken out of the town to an unclean place" (Leviticus 14:43-45, NIV). The biblical remedy for reappearing mold was to tear the house down and to remove the contaminated materials. Though modern mold remediation doesn't require quite such drastic measures, the desired outcome is substantially the same; to remove the contaminating substance and keep it from returning.

Thousands of years later during the Victorian Era, bad air had also had a moral component and was described as evil. Benjamin Franklin wrote, "I am persuaded that no common air from without is so unwholesome as the air in a closed room that has been often breathed and not exchanged." There were no CO2 meters available, but people knew when the air was bad. One of the primary culprits of poor air quality was combustion from heating and lighting. Burning candles and lighting fires created an unpleasant and unhealthy environment. Various technologies to control combustion were implemented over the past century to reduce soot indoors, but combustion from cooking indoors is still a cause of poor indoor air quality today.

Electricity: Soot-Free Lighting

Electric lighting completely changed the way interior spaces were lit. Before electricity, "all lights considered so far depend on a flame. If electricity could be used to produce light, there was the possibility of new light sources that would not depend on combustion, would not vitiate the air in a room by using up the oxygen, and would not leave a deposit of soot" (Bowers, 1998, pg. 63). Combustion still existed but was relocated from the indoor environment to an external coal burning power plant. Sources of energy were further controlled by humans as energy could be stored for later use.

Candles were invented by the Phoenicians before 400 A.D. and remained the only source of artificial indoor light until 1783 when the oil lamp was invented by Ami Argrand, a physicist from Geneva (Rybcynzski, 1986, pg. 138). The oil lamp was modified, improved, and remained the primary source of indoor artificial illumination. Innovations in lamps continued throughout the century with the kerosene lamp in 1858 and the discovery of petroleum in 1859 (Rybcynzski, 1986, pg. 138). However, it was a not a better lamp that would dominate the American interior, but the invention of the electric light bulb. While the history of the lightbulb is controversial and complex, most credit is given to Thomas Edison and his team. While they weren't the first to invent electric light, they commercially manufactured light bulbs and released this new product to the public in the 1880s. The gradual and widespread adoption of electric lightbulbs improved the indoor air by removing indoor combustion from lamps and candles. By 1927, over 60% of homes in America had electricity (Rybcynzski, 1986, pg. 153). The widespread use of electricity allowed for a combustion-free interior.

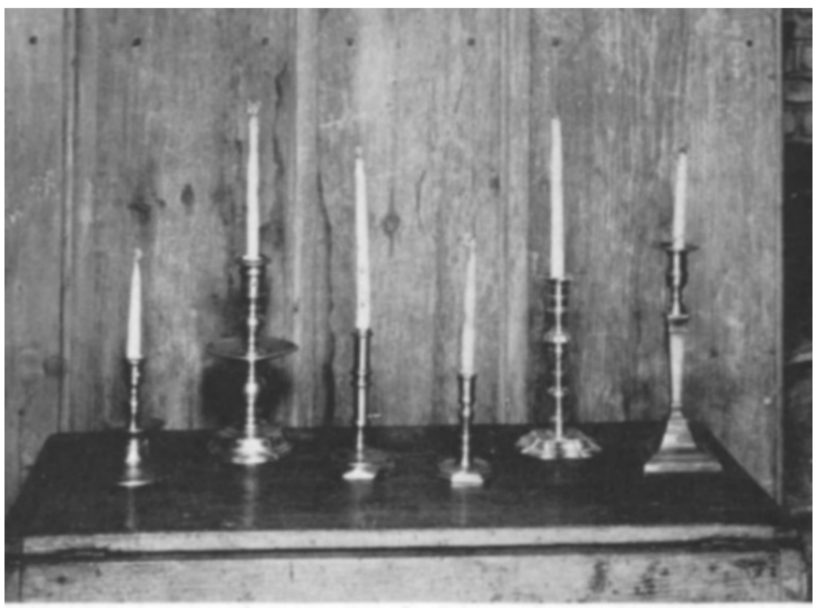


Figure 3.1: American Candlesticks from 17-18th c.
Source: Davidson

Heating History: Towards a Combustion Free Interior

Burning wood was the only way to heat a home for centuries. Eventually, the fireplace was designated and although it satisfied emotional needs, fireplaces are inefficient and create a smoky indoor environment. “Over the course of the last 250 years Americans made a transition first from open hearths to cast iron stoves and then from cast iron stoves to coal fired furnaces and then from coal fired furnaces to gas, oil, or electric forms of central heating” (Cowan, 1987, pg. 264). A significant innovation was the Franklin Stove in 1741 that addressed both efficiency and emissions as well as safety. Figure 3.2 shows the strategic placement of the Franklin Stove. “Stoves were an innovation – and they would have made a large difference in the thermal comfort of the house, not the least because, unlike the hearths, they did not fill the room with smoke” (Rybczynski, 1986, pg. 47). It took some time before stoves became widely used, but eventually they replaced open hearths. The stove kept the smoke trapped and vented out, improving the quality of the indoor air. Heating and cooking became separate functions and the stove was eventually replaced by the invention of the furnace in 1885. “The more modern house was heated by furnace in the basement which circulated hot water to radiators located below the windows in each room” (Rybcynzski, 1986, pg. 165). The furnace further reduced combustion in the home. “By the last quarter of the century, most Americans enjoyed the benefits of automatic central heating and relatively clean, more or less automatic cooking” (Cowan, 1987, pg. 267). Through innovations in both cooking and heating, an open flame was not required to keep building occupants warm.

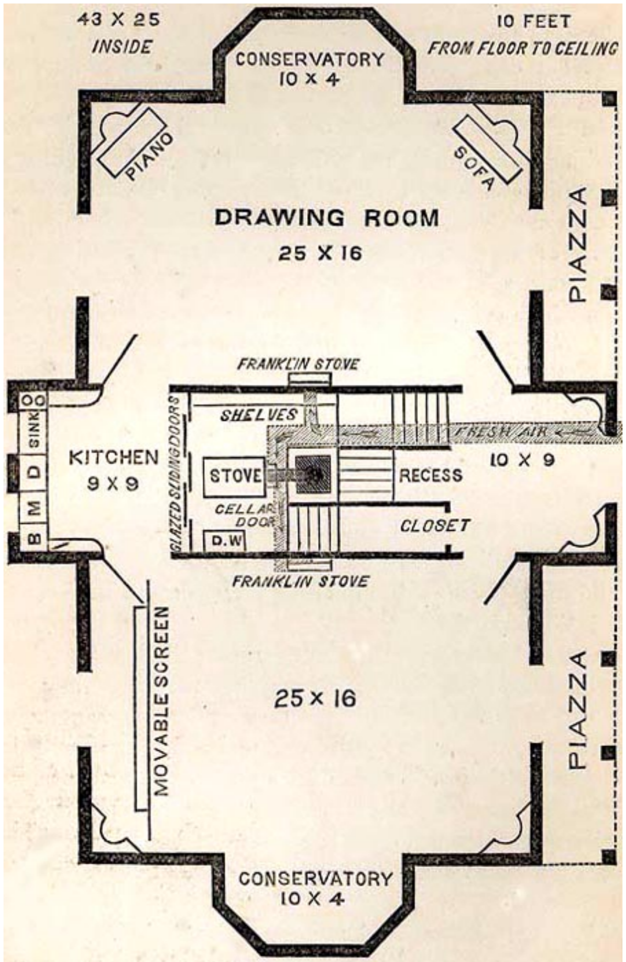


Figure 3.2: The American Woman's Home
Source: Beecher and Stowe, 1869, pg. 28

The Mechanization of the Home

The home transitioned from the domestic realm to the realm of science and engineering. "The arrival of gaslight and ventilation, flawed at these technologies were, signified the beginning of the rationalization, and more over the mechanization, of the home" (Rybczynski, 1986, 145). Before mechanical air conditioning, homes were kept cool through various means including natural ventilation. Homes were designed with apertures in specific locations on the building façade to take advantage of natural breezes. Overhead ceiling fans made their appearance above southern outdoor patios in the 1890s (Rybczynski, 1986, pg. 152). In 1902 William Carrier and his team invented Air Conditioning (AC). Homes were cooled mechanically and were designed differently with the invention of AC. Previously, a building was designed with a shallow interior to allow air to ventilate and light the space, but now the interior could be deep because mechanical AC and electric lighting could reach the middle of the building. The indoor environment was easier to control than the outdoors. In a 1960s commercial for a gas air conditioner, popular American singer and actress Dinah Shore said, "humidity controlled, dust and pollen filtered, my indoor climate is always perfect." Perfection was achieved through mechanical control of the indoor environment.

Figure 3.3: Argos Gas Air Conditioner, 1960
Source: Youtube

With AC, homes were designed to be as airtight as possible to prevent the leakage of conditioned air. Previously, homes were not airtight and breathed by taking advantage of cross breezes. "19th Century houses, which in any case were not particularly airtight, were equipped with air ducts and ventilating flues" (Rybczynski, 1986, pg. 136). Without a natural flush of materials, toxins can become trapped in a building. Outdoor air is sealed off because it contains natural contaminants like dust and pollen. Once homes were sealed to keep the AC inside, everything else including any toxins are also sealed inside. People were becoming disconnected from nature in part because of their lifestyles but also because the indoors of homes continued to become separated from the outdoors. With a temperature controlled indoor environment, the outdoors seemed unpredictable and often uncomfortable. Air conditioning continues to become more popular as seen in figure 3.4 below.

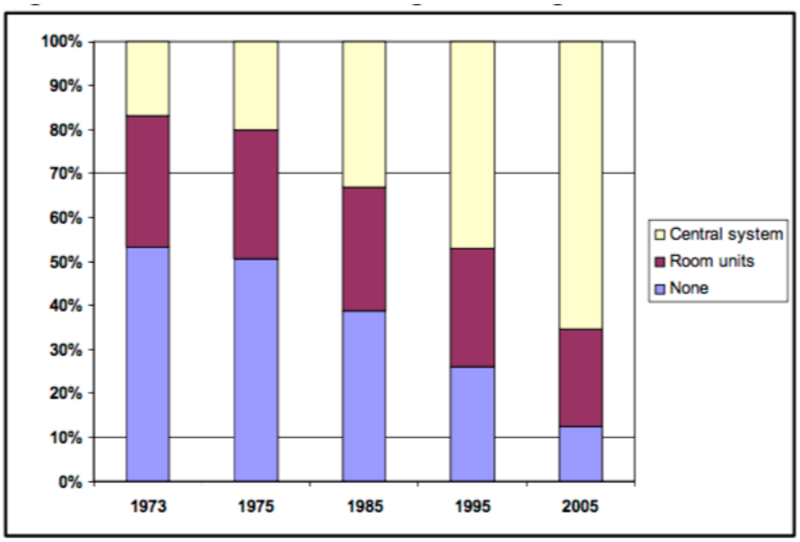


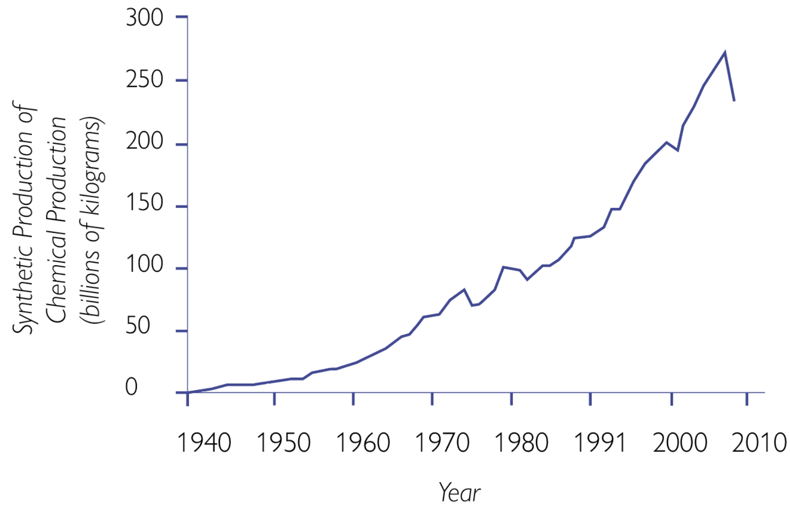
Figure 3.4: AC in Homes from 1973-2005
Source: US Department of Housing and Urban Development

History of Synthetics and New Chemicals

"As the tide of chemicals born of the Industrial Age has arisen to engulf our environment, a drastic change has come about in the nature of the most serious public health problems."

- Rachel Carson, *Silent Spring*, 1962

The establishment of the Federal Home Association (FHA) and mortgages facilitated mass home ownership in America starting in the 1920s. Communities of homes like Levittown were built near the east coast of America between the 1940s-1960s. Merchant builders on the west coast in Los Angeles built entire homes communities during the same time period. These homes were built using products made with synthetic materials-surplus from WWII. The American government subsidized the plastic industry during WWII and after the war incorporated plastics into a variety of consumer products from Tupperware to building materials. "The development in recent years of synthetic resins has led to entirely new building materials and techniques" (Davey, 1961, pg.221). Chemical sealants became widely used by the 1960s and replaced natural mud that was used for centuries. Synthetic paints are popular today because of their performance.



Synthetic production of chemicals continues to rise.

Figure 3.5: Chemical Production Since 1940
Source: Neel and Sargis, 2011

These new materials have had a negative impact on indoor environmental quality and were made from chemicals that were not tested for human safety. Because safety was not tested, only the benefits of performance were known, and the risks were unknown. The 1976 Toxic Control Substance Act set guidelines and regulations on new chemicals, but many old chemicals that have not been tested for human safety are still being used to make new products. Had the government not subsidized the plastic industry, it may have been harder for plastics to compete with natural materials. Figure 3.5 above shows the increase in chemical production, which led to new building materials.

Combustion History

Combustion still causes issues indoors. Combustion from cooking in unventilated spaces is a problem for the developing world while the developed world faces problems from chemical contamination. However, combustion has overall decreased indoors from a variety of innovations in cooking, heating and lighting. The most recent issues arise from synthetic contamination. Demands for low maintenance materials and for comfort have become problematic for indoor air quality. Carpets collect and store dust while low maintenance materials like vinyl post risks to human health because vinyl is a carcinogen which means it can cause cancer. Contamination from both smoke and chemicals pose different problems for the indoor environment. The figure below shows that as interior combustion decreased, chemical production increased.

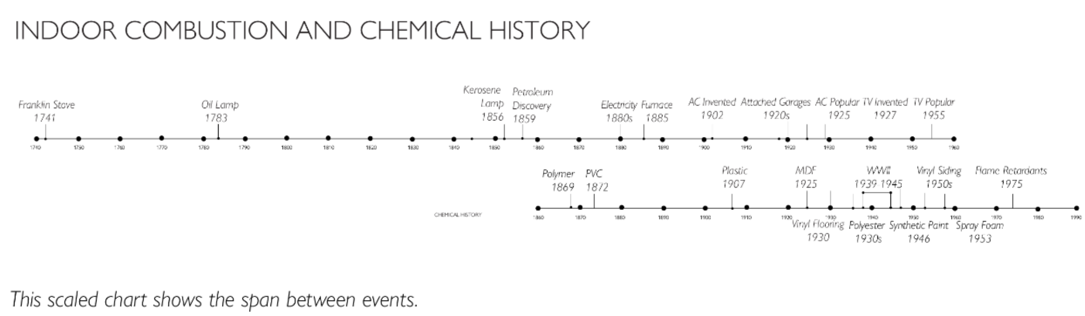
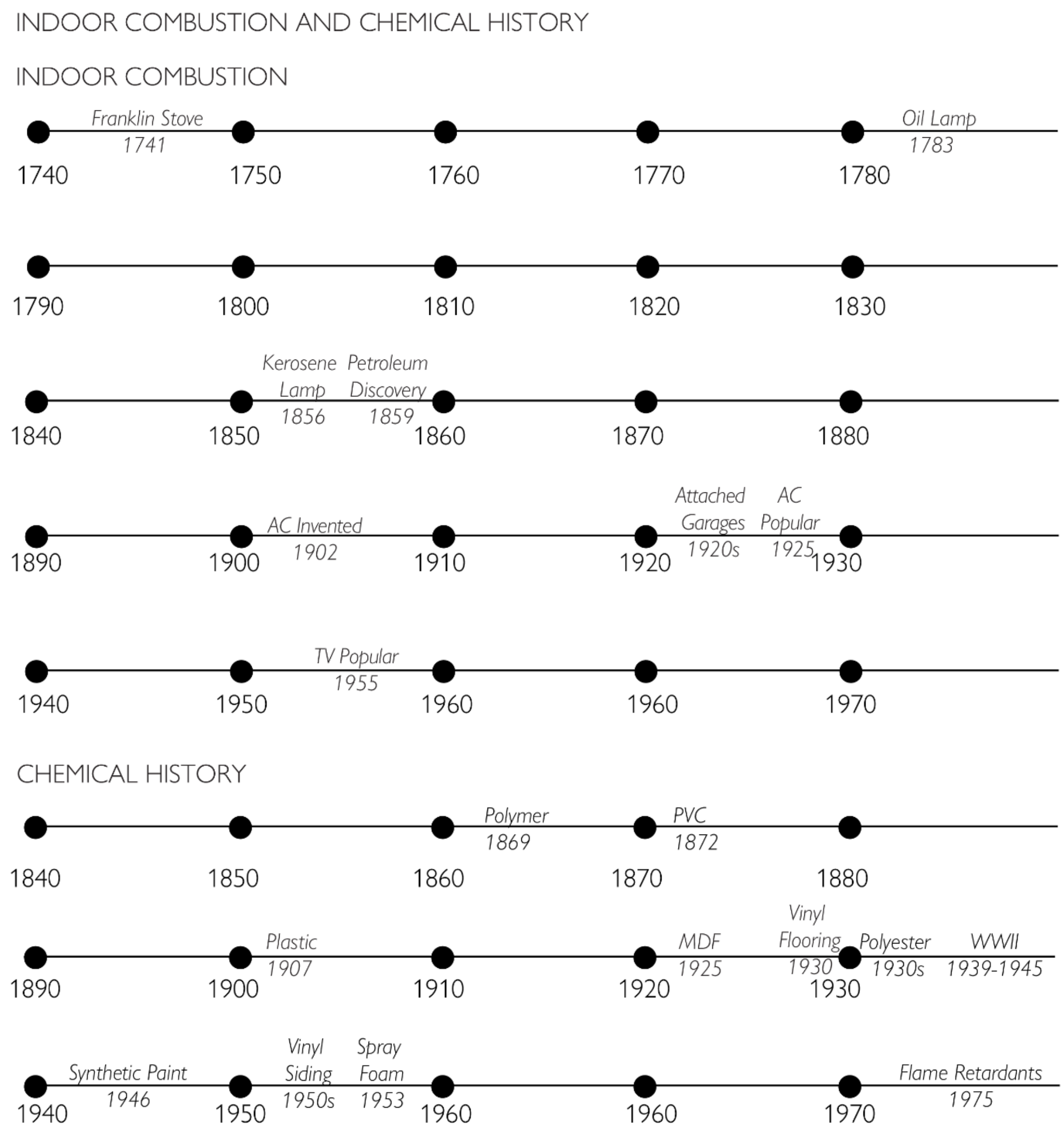


Figure 3.6: Interior Combustion and Chemical Contamination



Over time, interior combustion decreased throgh a series of heating and cooling innovations. A rise in chemical production led to new materials made from syntehtic ingredients

Figure 3.6, continued

Competition

Competing ideologies of sustainability have been present since the term was first used. Some of the first initiatives behind green building were originally to reduce energy consumption. Buildings require energy in their construction, operation, and demolition. "In 2017, about 39% of total U.S. energy consumption was consumed by the residential and commercial sectors…and on average, space heating uses the most energy and ventilation uses about 10%" (U.S. EIA, 2018). Because buildings use so much of the national total energy, there are many opportunities to reduce total energy by reducing building energy consumption. Today, global climate change is one of the main reasons we try to reduce energy usage. The 1973 oil embargo was America's first energy crisis. The crisis did not happen all at once but was the result of a variety of factors:

> "It stemmed from the fact that the nation was, and continues to be, in a period of transition from a long era of cheap and abundant indigenous energy and neglect of environmental consequences to one of scarcity of acceptable clean fuels, growing dependence on foreign energy imports, inadequate development of alternate clean energy sources and a growing interest in maintaining, or enhancing, environmental values" (Morton, 1973, pg. 65).

During the 1970's, air exchange rates were decreased to reduce energy, but this led to poor indoor environmental quality (Allen, 2016). This example demonstrates the complex nature of sustainability. The 1973 oil crisis was not primarily about environmental stewardship, but rather a response to a lack of available resources and an increased price of gas. There was a tangible scarcity that could be seen in the long lines at gas stations. Energy was reduced because that was the only option. Today, the threat of global climate change is not so tangible because we cannot see the energy crisis. Unless we see ice caps melting, there is little direct evidence of climate change. Inexpensive energy is available, but the choice to reduce energy consumption is mostly due to environmental and economic concerns. We are currently experiencing an artificial reality of an infinite supply of energy.

Figure 3.7: Gas Shortages in the U.S.
Source: Getty Images

The 1973 oil crisis threatened the American way of life, which was previously thought to be uncompromisable. As a result, millions of Americans began to reshape the way they worked and played. A New York Times article interviewed Americans to see how they responded to the energy crisis.

> "Mr. Ramsey, an Atlanta engineer, mobilized. He replaced his fuel-hungry furnace. He began insulating his entire house. He installed a clock thermostat that

automatically dialed the heat down at night. Sweaters became dear to him. As fuel prices crept higher, he grew more frugal. Two years ago, he stopped driving to work. The 50-year- old Mr. Ramsey now pedals the 13 1/2 miles on a bicycle, saving himself $20 a week on gas. He finds the pumping really wakes him up. Leisure trips are rationed" (Kleinfield, 1983).

The mass mobilization of Americans responding to the energy crisis can be compared to Americans who mobilized during WWII. People changed their lifestyles and behaviors. Americans wore sweaters instead of turning on the heater and businesses also reduced energy in the commercial sector. Today, Mr. Ramsey would be an environmental hero. As a society, we do not value thrift the same way we did in the 1970s. People were truly fearful in the 1970s and today most Americans remain somewhat calm about the energy situation. Today, economic incentives are the driver of sustainable initiatives and rebates for solar panels are a key reason why people install them on their homes. Money is the primary driver for such initiatives and the environment benefits are secondary. The most recent climate crisis has not had the same level of urgency and participation for most Americans as the oil crisis in the 1970s.

In order to reduce energy consumption in buildings, air exchange rates were lowered. "In 1973, the oil embargo led building designers to make buildings more airtight, with less outdoor air ventilation, in order to improve energy efficiency. The ventilation was reduced to 5 cfm/person. This reduced ventilation rate was found to be inadequate to maintain the health and comfort of building occupants" (Joshi, 2009). Now, The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) recommends 15 cfm/person at a minimum. "In part as a reaction to the energy crisis of the mid- 1970s, ASHRAE published Standard 62-1981, Ventilation for Acceptable Indoor Air Quality, to replace the 1973 standard." (Stanke, 1999, pg. 40). The 1973 standard was minimally acceptable and not for optimal comfort and health. During times of crisis, human comfort was compromised. Ventilation rates should be based on science and not politics.

United States Weatherization

That same year, The Energy Conservation and Production Act of 1976 promoted the weatherization of homes to reduce energy. Low-income families were provided with weatherization to decrease their monthly energy bills. "Tightening houses – that is, reducing the amount of outside air being pulled into the living space and heated or cooled air leaking out – is one of the principle goals of weatherization. However, it is important not to make a building too tight" (Manuel, 2011, pg. 11). When a home is too airtight, harmful chemicals (both natural, like radon and mold, and synthetic chemicals) can become trapped inside the building. With the introduction of air conditioning, homes were designed to be airtight. This prevents conditioned air from escaping the building and unconditioned air from entering the building. While this does prevent air leakage, it also traps contaminants in a space. Reduced air exchange rates, new synthetic chemicals, and airtight buildings led to unhealthy indoor environments.

Figure 3.8: U.S. Weatherization Logo
Source: U.S. Department of Energy

Sick Building Syndrome

Buildings were designed to be airtight to keep conditioned air inside and unconditioned air outside. At the same time, homes were built using new synthetic materials with unknown health effects. The 1973 energy crisis led to decreased ventilation rates which further compromised human health in the indoor environment. “A 1984 World Health Organization Committee report suggested that up to 30 percent of new and remodeled buildings worldwide may be the subject of excessive complaints related to indoor air quality” (U.S. EPA, 2014). The term "Sick Building Syndrome" was coined by the World Health Organization (WHO) in 1986. Building occupants complain of symptoms associated with acute discomfort, e.g., headache; eye, nose, or throat irritation; dry cough; dry or itchy skin; dizziness and nausea; difficulty in concentrating; fatigue; and sensitivity to odors (EPA, 2014). Usually symptoms disappear after leaving the building. When people experience these symptoms, they are less productive, and their health is compromised. Inadequate ventilation was the primary culprit followed by chemical contamination. “It also appears that SBS and BRI are more frequent in newer air-conditioned buildings” (Guzowski, 2001, pg. 307). The airtight home of the 1950s plus the synthetic materials from the 1940-1960s combined with reduced ventilation in the 1970s led to sick building syndrome and building related illness. As shown in Figure 3.9, SBS did not appear out of nowhere, but was the result of many different factors.

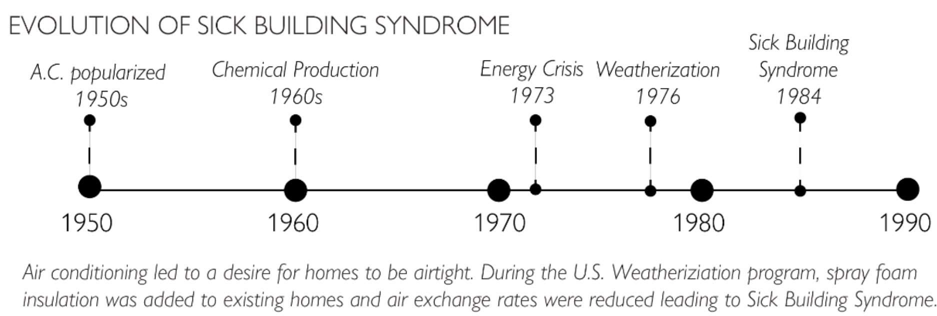


Figure 3.9: The Evolution of Sick Building Syndrome

Regulation

If there are regulations for food and drink, one might argue that there should also be regulations for indoor air because we spend so much time indoors and we breathe more air pound per pound than we consume in both food and drink (Siegel, 2011). When architects and designers create architectural drawings, they must follow local and national building codes. These codes are designed to maximize building occupant safety and reduce chance of injury. As stated in the introduction, the EPA listed indoor air as a top human threat and indoor air is 2-5x more polluted than outdoor air (U.S. EPA, 1987). However, there are neither codes nor regulations for residential indoor air quality, where we spend the majority of our time. While more codes and regulations may create fatigue for designers, a voluntary guideline or standard may help designers choose appropriate materials.

While there are almost no regulations for indoor air, there is regulation for outdoor air. Outdoor air was first federally regulated in 1955 with the Air Pollution Control Act. This was significant because it was the first time that the federal government recognized that there is a link between human health and air quality. President Lyndon B. Johnson signed the 1967 Clean Air Act which expanded upon the previous air act. In 1970, another Clean Air Act was signed by President Richard Nixon and the focus was on reducing industrial and mobile sources of pollution. “After the Clean Air Act's first 20 years, in 1990, it prevented more than 200,000 premature deaths, and almost 700,000 cases of chronic bronchitis were avoided” (U.S. EPA, 2010). If this was the result from addressing outdoor air, there would also be positive benefits if indoor air was addressed. Amendments to the Clean Air Act were made in 1977 and 1990.These regulations have been beneficial for human health and are significant because outdoor air quality plays a role in indoor air quality. However, we predominantly are an indoor species and spend more time indoors than outdoors. Indoor air should be equally as healthy if not healthier than outdoor air given our chronic exposure to indoor air.

Figure 3.10: President Nixon Signing the Clean Air Act in 1970
Source: Associated Press

Indoor Environment Regulation

The Occupational Safety and Health Administration (OSHA) has set strict guidelines and regulations to improve the health and safety of workers. “Although OSHA does not have IAQ standards, it does have standards about ventilation and standards on some of the air contaminants that can be involved in IAQ problems.” (OSHA, 1994). Employers are required to provide workers with a safe and healthy workplace. The 1970 general duty clause requires that employers “shall furnish to each of his employees’ employment and a place of employment which are free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees” (OSHA, 1970). OSHA regulations are for work environments only.

The only non-work-related indoor air quality regulations are related to smoking in public places. Architect and writer Witold Rybczynski stated, "public smoking has lasted about forty years, but it is likely that before long it will cease altogether, and we will return to the time when it was considered impolite to smoke in the company of others" (Rybczynski, 1986, pg. 217). His prediction was true and California was the first state to ban smoking in public places in 1995. Many states followed in the 2000s, and Alaska, the most recent, banned smoking in public places in 2018. While this is an improvement, this regulation only deals with one contaminant in public places.

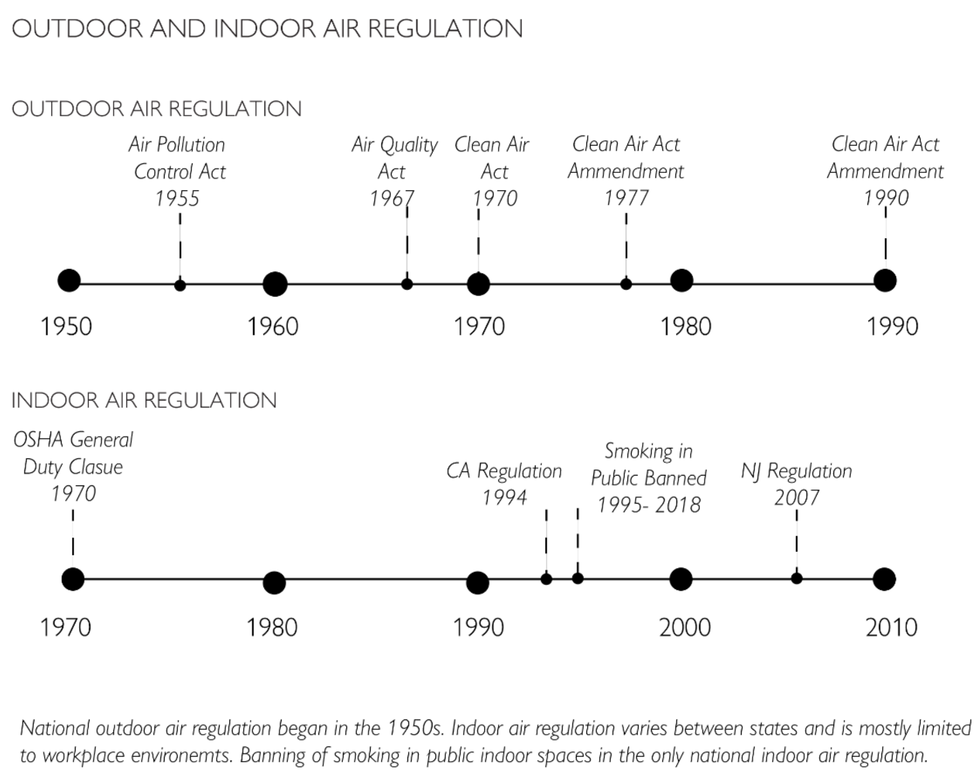


Figure 3.11: Outdoor and Indoor Air Regulation

California and New Jersey are the only states with indoor air regulations. In 1994, California set indoor air quality standards for non-industrial work environment (OSHA, 1994). In 2004, New Jersey adopted (N.J.A.C. 12:100-13) for existing building occupied by government workers. (N.J.D.O.H., 2018) These regulations are related to work environments. There are no regulations that directly regulate indoor air quality in the home, where we spend a majority of our time. Since there are no legal regulations for the home, it is the responsibility of builders, architects, and designers to ensure that the home is a healthy place. Figure 3.11 shows that outdoor air regulation started earlier and is implemented on a national level while indoor air regulation still varies between states and began later.

Standards

"The nice thing about standards is that there are so many to choose from"

-Andrew Tanenbaum, *Telecommunications Act of 1981*

The toxicity of the indoor environment is not addressed by mandatory codes. Figure 3.12 below shows how extensive codes and regulations are for buildings in California. While California is known for extensive codes, building codes in all states are extensive. These codes are designed to reduce the chance of catastrophe but do not protect the long-term health of a building occupant. These regulations typically fall into two categories: proscriptive (negative) or prescriptive (positive). Building codes vary between city, state, and country and are constantly changing. The process of learning and implementing building codes is often mundane, confusing, and tiresome. Because codes focus on minimizing maximum regret, acute fatal catastrophe is more strategic to prevent than long term health problems. “Today, communities face problems that have arisen because standards intended for health and safety have become disconnected from the original rationale for their existence” (Eran Ben Joseph, 2005, pg. XVI). With such a large volume of codes, more codes to protect human health may not be well received.

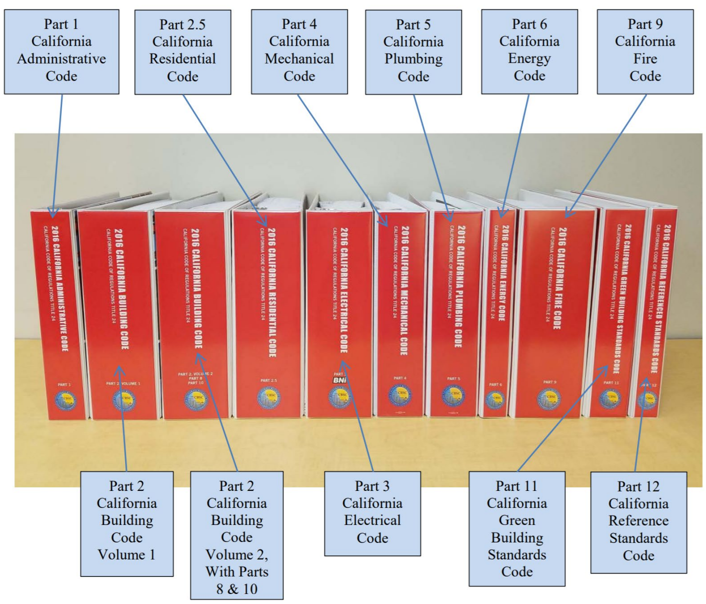


Figure 3.12: California Building Codes
Source: Aleksandra Jaeschke

Voluntary Standards

While there are no regulations for residential IAQ, there are voluntary standards for both building and products. Standards for buildings are: Leadership in Energy and

Environmental Design (LEED), Energy Star, WELL Building institute, Living Building Challenge (LBC), and Indoor airPLUS. Standards for products are , Healthy Building Network and the Pharos Project, LBC red Free List, Perkins + Will Transparency, Healthy Products Declarations and Greengard Some of these standards address the whole building while others address specific building materials. Even though many voluntary standards exist, most homes do not follow these guidelines. “The voluntary nature of many standards makes it difficult to develop momentum unless built in incentives promote compliance” (Timmermans, 2010, pg. 79). Typically, green construction can cost more than conventional construction and most homeowners place budget as a priority because there is little awareness that our homes may pose risks to our health. Figure 3.12 shows that these standards all began around the same time.

New Conditions

Historical events and regulations can offer insight to current indoor air quality. Natural buildings were subject to dust and mold, but there was no synthetic chemical contamination. We burned fires to stay warm and to cook food and lit candles to see. With the invention of electricity, indoor combustion for heating and lighting decreased and now the most common source of contamination from combustion is associated with cooking using natural gas. While some smoked indoors, this was eventually banned in public places. Over time, there has been less combustion in the indoor environment due to technological advances. However, there has been an increase in chemical contamination for the same reason. Synthetic chemical production began at the end of the 19th century and new synthetic materials were available as consumer products. Towards the middle of the 20th century, new advancements in science and technology led to more synthetic chemical production. New chemicals in an airtight and air-conditioned space led to sick building syndrome and modern regulations and standards have not yet addressed human health in residential architecture, where we spend the most time indoors.

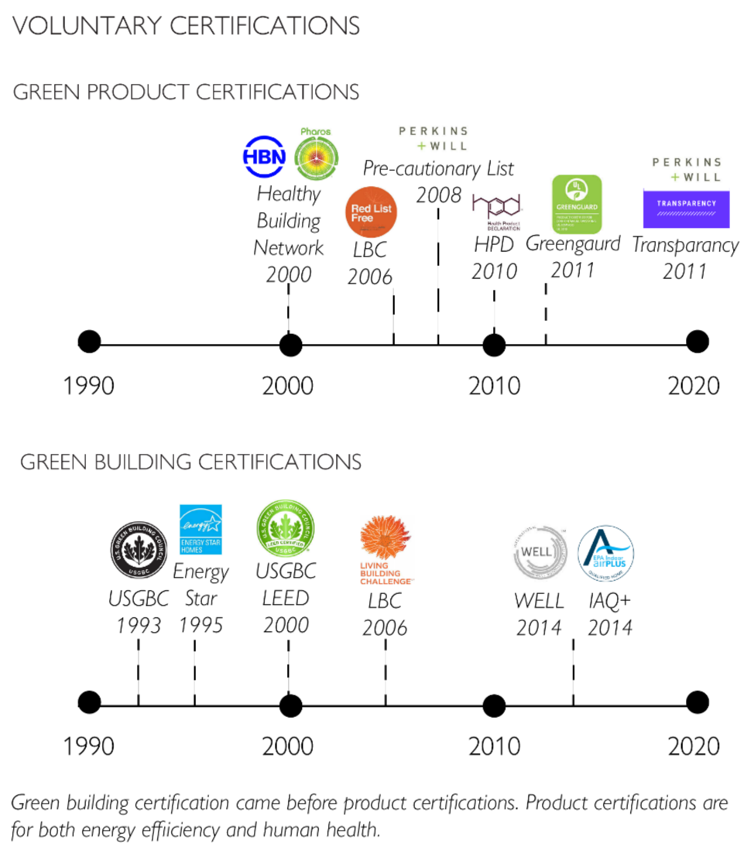


Figure 3.13: Voluntary Green Building and Product Standards

Chapter 4: Building Material Analysis

"Materials selection is easily the most difficult and contentious area of sustainable construction."

- Charles Kibert, *Defining an Ecology of Construction,* 2002

Building Materials Introduction

Building materials directly impact indoor air quality because each material will off gas during its lifecycle. A building material can either positively or negatively impact the indoor air and the health of occupants. Some building materials are made from toxic ingredients and while they may perform well, they also pose a risk to human health. The desire from clients and occupants for high performing and low maintenance materials had led to many designers and architects specifying these new materials. For example, stain free carpets may require less maintenance, but it is difficult for a designer to establish whether the material benefits outweigh the risks. While there are no guides nor standards for residential indoor air quality, best practices should be used to specify materials.

Historically, buildings were made from local and natural materials and materials remained somewhat similar for centuries. Stone, earth, wood, and brick were used as for thousands of years. Sealants like mud were used to keep water out of buildings. There was little to no waste created during the construction process because materials were natural and compostable. However, we now live in a post-industrial society and post-industrial building materials have replaced many pre-industrial building materials. "The transformation of pre-industrial, indigenous settlements into mass urban society is irreversible. Our modern path to sustainability lies forward, not behind us" (Campbell, 1996, pg. 302). While we can learn from ancient building materials, we cannot go back in time. A single contemporary building can use thousands of different materials from around the world. Most new construction is built from materials that were invented in the last century

Post WWII Materials

There is a distinction in the way buildings were built before and after World War II. Charles Thomsen, author of *100-Year buildings, 10-Year Interiors* wrote, "pre-WWII buildings are often in better shape than more modern ones. Their terrazzo floors, tile partitions, and brick walls will have resisted abuse better than the curtain wall, metal stud and drywall construction used in the last four decades of the 20th century. The sealants and adhesives to keep the water out have proved less lasting than the geometric methods of overhangs and 'down and out' material journey" (Thomsen, pgs. 5-6). These sealants and adhesives also pose risks to human health because most modern sealants and adhesives contains VOCs.

While there are many regulations regarding outdoor air quality, there are no governmental regulations regarding residential indoor air quality. In *Citizen Virtues in a Technological Order,* Langdon Winner writes about the risks and benefits of a new chemicals in the environment. Winner asks, "How can one weigh the risks of introducing a new chemical into the environment as compared to the benefits of its use?" (Winner, 1992, pg. 65). With proper scientific testing, we can know the risks of certain chemicals, but many of the chemicals present in the built environment have not been tested for safety. William McDonough, author of *Cradle to Cradle*, states, “of the approximately eighty thousand defined chemical substances and technical mixes that are produced and used by industries today, only about three thousand so far have been studied for their effects on living systems” (McDonough, 2002, pgs. 41-42). Many building products contain chemicals that have not been tested for safety. It is therefore the responsibility of designers and architects to make appropriate selections. This can be challenging because human health and chemistry are usually not part of an architectural or design curriculum.

Designers should be cautious when specifying building materials made from chemicals that have not been tested for safety. When buying food or body care products one can check the label on the product to see the ingredients. When choosing a building material, it is equally important to check the ingredients since they impact the air we breathe. Materials Safety Data Sheets (MSDS) list materials ingredients and should be referenced when selecting a product. However, product manufacturers are not required to disclose a full ingredient list in their products for proprietary reasons. Designers should choose products that disclose the full ingredients list. If designers and architects only specified materials with a comprehensive MSDS, manufacturers would have more incentive to be more transparent.

Building Materials Categories

Each new building contains thousands of different materials that are built in layers. In an article called *Defining a Construction Ecology*, the authors list the categories of building products:

1. Manufactured, site-installed commodity products, systems, and components with little or no site processing (boilers, valves, electrical transformers, doors, windows, lighting, bricks)
2. Engineered, off site fabricated, site-assembled components (structural steel, precast concrete elements, glulam beams, engineered wood products, wood or metal trusses)
3. Off-site processed, site finished products (cast-in-place concrete, asphalt, aggregates, soil)
4. Manufactured, site-processed products (dimensional lumber, drywall, plywood, electrical wiring, insulation, metal and plastic piping, ductwork)
5. Manufactured, site installed, low mass products (paints, sealers, varnishes, glues, mastics) (Kilbert et al, 2002, pg 25).

Each material has a different lifespan and ages in a different way. The aging of the materials may or may not work in a cohesive manner. Interior finishes play a significant role in indoor air quality because they are the final layer of a structure. Interior finishes include adhesives, flooring material, wall finishes, and ceiling finishes. "Interior finish materials provide a primary method of improving a building's sustainability because they are one of the main sources of potential indoor air pollution and are typically replaced several times over the life a building" (Ballast, 2019, pg. 21-13). While their total volume may be small relative to other building components, interior finished selection is paramount. The following materials will be analyzed from both and environmental and human health perspectives: Insulation, Flame Retardants, Medium Density Fiberboard, Carpet, Vinyl, and Paint. These materials were chosen because they are commonly used and impact the indoor environment.

Insulation

In the 1970s, Americans changed their behaviors in response to the energy crisis. Today, we have found creative ways to reduce energy without changing our behaviors. Spray foam insulation has become a popular choice for building insulation. “Spray-on polyurethane products containing isocyanates have been developed for a wide range of retail, commercial, and industrial uses” (U.S. CDC, 2014). According to *Spray Foam Austin*, a Texas based insulation company, “There is no better home insulating material that can seal your home from air and moisture intrusion, save on costly utility bills, strengthen your home, and protect your family’s health from dangerous mold than spray foam insulation” (Spray Foam Austin). Their website claims that spray foam can improve indoor air quality by keeping natural pollutants like dust out of the home. In addition to reducing energy bills, spray foam can also reduce waste. “Injected polyurethane is an ideal material for thermoacoustic renovations of facades and dividing walls between dwellings” (Saez, 2018, pg. 2985). The technique of injection produces less waste than conventional techniques, but polyurethane poses health risks to humans. In order to reduce energy usage, homes are insulated to maintain stable temperatures and reduce mechanical heating and cooling loads. While spray foam produced less waste than other types of insulation and reduces energy loads of a building, the benefits might not be worth the risk. “SPF is a highly-effective and widely-used insulation and air sealant. However, exposures to SPF's key ingredient, isocyanates and other SPF chemicals in vapors, aerosols, and dust created during and after installation, can cause: Asthma, Sensitization, Lung damage, Other respiratory and breathing problems, skin and eye irritation.” (U.S. EPA, 2017) The Center for Disease Control (CDC) states:

> Isocyanates are powerful irritants to the mucous membranes of the eyes and gastrointestinal and respiratory tracts. Direct skin contact can also cause marked inflammation. Isocyanates can also sensitize workers, making them subject to severe asthma attacks if they are exposed again. There is evidence that both respiratory and dermal exposures can lead to sensitization. Death from severe asthma in some sensitized subjects has been reported. Workers potentially exposed to isocyanates who experience persistent or recurring eye irritation, nasal congestion, dry or sore throat, cold-like symptoms, cough, shortness of breath, wheezing, or chest tightness should see a physician knowledgeable in work-related health problems. (U.S. CDC, 2014)

Even though spray foam insulation is harmful to human health, it continues to be used as insulation in buildings and other products. “Spray polyurethane foam (SPF) sales topped $1 billion in 2015 by most estimates after another solid year of growth due to increased activity in construction and home improvement projects.” (Kavanaugh, 2016) The 2009 American Recovery and Reinvestment Act continues to provide weatherization assistance using spray foam. “The U.S. Department of Energy’s (DOE) Weatherization Assistance Program (Weatherization) reduces energy costs for low-income families by increasing the energy efficiency of their homes, while ensuring their health and safety.” (DOE, 2009) It is interesting that they claim to ensure their health and safety while the materials used in weatherization were proven harmful to human health by the CDC. Are the benefits of spray foam insulation worth the risks? In this case the risks seem to outweigh the benefits. While this type of insulation can reduce energy and reduce landfill waste, it is too dangerous to human health to be considered sustainable. In addition to harming the health of building occupants, construction workers are exposed to toxins in high concentrations. At some point, most materials will be discarded, and humans will again be exposed to the material. Humans are impacted at all stages of a material's life cycle. In order to determine the best practices, each material must be selected carefully. The weatherization program targeted low-income families. They did help these families reduce their energy bills but also exposed them to toxic chemicals with the insulation. Building occupants are only one group of people impacted by a certain material. Figure 4.1 shows the protective gear that a spray foam installer wears to avoid toxicity.

Figure 4.1: Spray Foam Insulation Installation
Source: Walls and Ceilings Magazine

Certain conventional building materials and methods are harmful to human health. Fortunately, designers can specify health alternatives that address both humans and the environment. There are ways to reduce energy without compromising indoor air quality. Smaller buildings will use less energy than larger buildings and natural ventilation can be designed. Building can also be designed to take advantage of local wind patterns. Spray foam insulation is just one type of insulation. When applied properly, it can reduce energy consumption and produces less construction waste than other types but there are many different types of insulation that are also efficient. For example, recycled denim can also reduce a home's energy bill and is safe to install. It will not compromise the health of the construction workers and will not compromise indoor air quality. Recycled wool is another option for residential application. Another issue with spray foam insulation is that it may prevent the recyclability of the wood and separating the materials could be dangerous. The full lifecycle of a material should always be considered.

Flame Retardants

Flame retardant (FR) chemicals are used in a variety of building materials and household products including foam, upholstery, mattresses, carpets, curtains, televisions, cables, wires, and insulation. Figure 4.2 shows the different products that use flame retardants. Flame retardant chemicals are used to suppress the spread of fire, but their effectiveness is questionable. While chemical companies claim that they do indeed suppress fire, other scientists and researchers have stated that their benefit is not worth their risk. The Chicago Tribune showed a six-part series called *Playing with Fire* where they outline the history of flame retardants and bring awareness to the role of the tobacco industry in the regulation of flame retardants. Flame retardant chemicals were first added to household products as part of California Technical Bulletin 117 in 1975. This bill was passed in part because of pressures from the cigarette industry as cigarettes left on couches were causing fires. Flame retardants are relatively new in the history of building materials. Historically, most furniture and building insulation were made from natural materials like straw, wool, feathers, and cotton. In the 20th century polyurethane was invented and now is used for both furniture and insulation. Foam is ubiquitous in modern furniture because it is inexpensive and feels comfortable. Foam also create an evenness in upholstery which was favored over the bumpy uneven look of natural materials. The new use of foam is relevant because flame retardants are added to the foam.

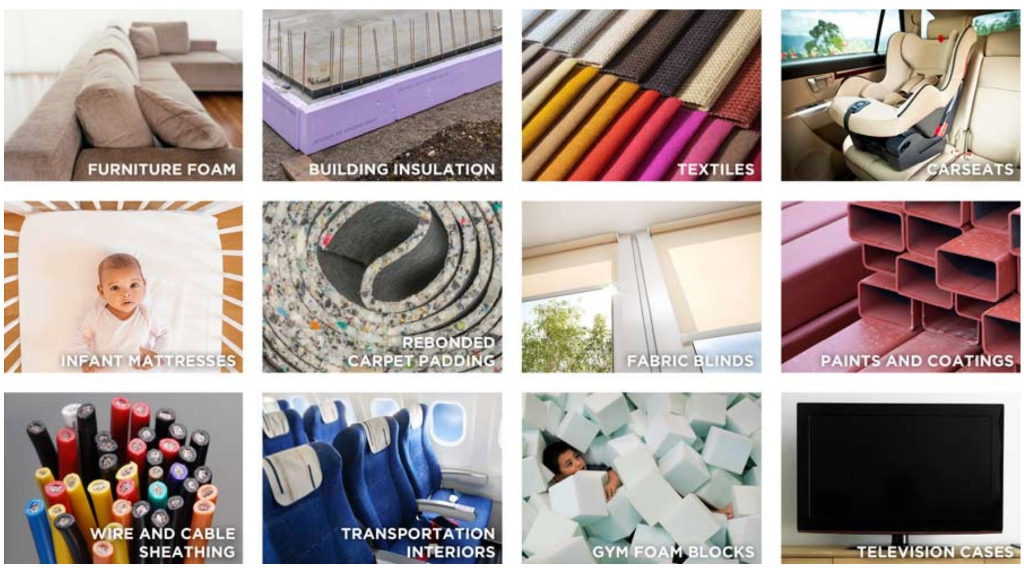


Figure 4.2: Flame Retardants in Everyday Products
Source: six classes of chemicals organization

Concerns over the health effects and the effectiveness of the chemical to suppress a fire have led to the update of CA TB 117 called CA TB 117-2013 and manufacturers are no longer required to use flame retardant chemicals in upholstery. Products still must meet fire suppression standards, but added chemicals are not required. However, many manufacturers still use chemical flame retardants. Polybrominated diphenyl ethers (PBDEs) are a type of flame retardants that were used in furniture and other products since the 1970s (Cowell, 2017). These have been phased out and sometimes are replaced with Firemaster 550®. Ideally the replacement chemical would be better for human health but sometimes the replacement chemical is just as harmful.

Flame retardants pose health risks for humans. “PBDEs and their hydroxylated metabolites appear to primarily target the thyroid system, likely due to their structural similarity to endogenous thyroid hormones… studies suggest that both should be considered endocrine disruptors” (Dishaw, 2014). The health effects of flame retardants go beyond disrupting the endocrine system. Firemaster® 550 (FM 550FM) was studied on rats in a laboratory. “Effects included increased serum thyroxine levels and reduced hepatic carboxylesterase activity, and advanced female puberty, weight gain, male cardiac hypertrophy, and altered exploratory behaviors in offspring. Results of this study are the first to implicate FM 550 as an endocrine disruptor and an obesogen at environmentally relevant levels" (Patisaul, 2013). FM 550FM and PBDEs are both considered endocrine disruptors. FM 550 is replacing PBDEs, yet they both pose similar health risks. Because of ethical reasons, a study like this could not be conducted on humans. “Available data, however, raise concern over the use of certain classes of brominated flame retardant” (Birnbaum, 2004). Researchers recommend further study of flame retardants.

Flame retardants are also added to textiles. It is well known that there are health risks associated with textile production, but the effects go beyond the factory to the human body. Also, the risks are more than just skin allergies. Researchers found in textiles the "presence of flame retardants, trace elements, aromatic amines, quinoline, bisphenols, benzothiazoles/ benzotriazoles, phthalates, formaldehyde, and also metal nanoparticles" (Rovira, 2018). Bedding products emit both VOC and SVOCs. They also emit "phenol, styrene, formaldehyde, phthalate and alternative plasticizers, and brominated and organophosphate flame retardants" (Boor, 2015). The synergistic effects of the mattress and pillows and sheets are unknown.

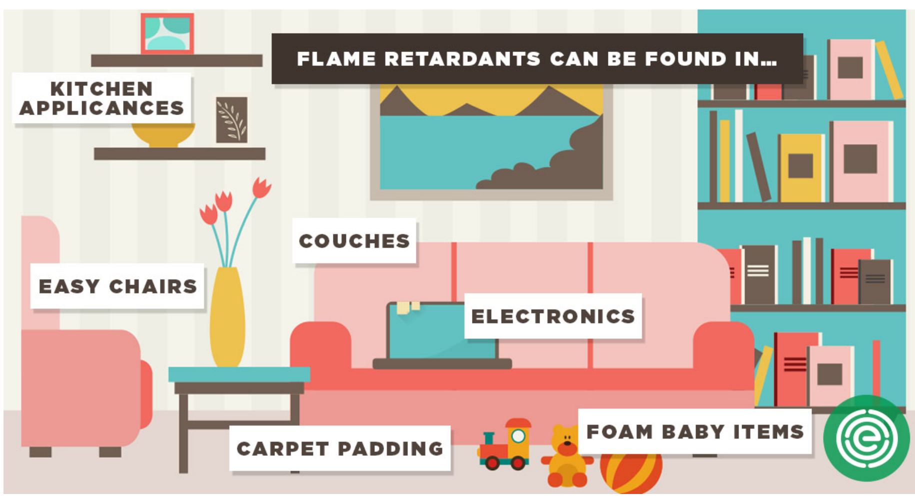


Figure 4.3: Flame Retardants in Household Products
Source: Environmental Working Group (EWG)

Flame Retardants and Air

Flame retardants impact indoor air quality. "Over the product lifetime, FRs slowly volatilize or escape from the treated materials and accumulate in indoor air and dust particles or escape to the outdoor environment" (Dishaw, 2014). This is particularly concerning because we keep furniture for decades and FRs can off gas during their entire lifetime. One of the reasons flame retardants can escape the material is the way the products are made. “During manufacturing, PBDEs and Firemaster 550® are added, rather than chemically bound, to the consumer products that they are intended to protect. Over time these chemicals are released into the indoor environment where they sorb to house dust” (Cowell, 2017). Indoor air quality is important because we spend a vast majority of our time indoors and furniture selection can impact indoor air quality. Firemaster® 550 (FM 550), a fire-retardant mixture used in foam-based products, was recently identified as a common contaminant in household dust. Many chemicals attach to dust particles in the air. Inhalation of dust can cause allergic type reaction but also toxic inhalation. “Flame Retardant emissions from mattresses containing polyurethane foam and viscoelastic memory foam (VMF) contain asthmatic agents” (Garrido, 2017). In addition to disruption the endocrine system, flame retardants can worsen asthma.

Flame retardants can disrupt the endocrine system and they also can impact intelligence. Since the 1970s, IQ has been dropping and researchers concluded that the decrease in IQ is due to environmental factors. (Cowell, 2017) It is hard to say exactly which environmental factors are causing the decrease of IQ, but some studies have found correlations. “Lower intelligence was associated with prenatal exposure to a highly chlorinated PCB” (Tatsuka, 2014) and “polybrominated diphenyl ether exposures were associated with 873000 lost IQ points” (Bellanger et al. 2015). A loss in IQ means that children will not have the ability to reach their full potential. The concerns with flame retardants are challenging because there are social impacts. Even though PBDEs are now being phased out, many households have old furniture that still contains PDBE's. "Researchers have also found that low-income residences tend to have higher levels of flame retardants in dust" (Birdbaum, 2004). As the foam in older furniture crumbles, flame retardant emissions are released into the air. "Indoor concentrations of multiple pollutants are elevated in low-socioeconomic status households" (Adamkeiwicz, 2011).

Most of the scientific studies stated that flame retardants are likely endocrine disruptors. Almost all researchers suggested further studies to confirm results. Air quality is impacted by flame retardants and this poses more challenges for low income residents as they may not be able to buy new furniture without flame retardants. Flame retardants are endocrine disrupting, associated with a decrease in IQ, and can cause asthmatic conditions. Fortunately, flame retardants are being phased out, manufacturers are advertising that they will offer flame retardant free furniture. In 2018, California approved a flame-retardant free insulation below grade. This product is not yet available as of 2019 but this shows that California is considering the health of building occupants, manufacturers, and fire fighters.

Medium Density Fiberboard

Medium density fiberboard (MDF) is a composite wood product. Other types of composite wood products include particleboard, plywood, and oriented strand board. MDF products are used in a variety of building products such as cabinets, floors, subfloors, and furniture. MDF has become popular because it is strong compared to its counterpart -particleboard. It is made from wood scraps or wood dust and glue pressed together under high heat. The final product is lightweight, durable, and relatively inexpensive. MDF is used widespread and available at most hardware stores. The glue that is used to bind the wood scraps or dust together is usually urea formaldehyde. It is common for formaldehyde to makes up around 15% of the finished product. Formaldehyde is a naturally occurring chemical that is also synthetically produced. The concern with formaldehyde is related to the dose and the time of exposure. "Exposure to formaldehyde can irritate the skin, throat, lungs, and eyes. Repeated exposure to formaldehyde can possibly lead to cancer" (CDC 2019). MDF dust is toxic and carpenters should be cautious when using this material.

Figure 4.4: MDF Cabinets
Source: Jack Rosen Custom Kitchens

MDF is a relatively new building material. The first North American MDF plant was built in 1965 in Deposit, New York (Spelter, 1996). MDF was mass produced by the 1980s and was advertised as a miracle material because of its lightweight and structural stability. MDF is ubiquitous in modern architecture. Researchers measured formaldehyde in the air and took 419 air samples from 53 homes in Louisiana. "Seventy four percent (312/419) of the samples had detectable amounts of airborne formaldehyde. Of the 312 positive samples, approximately 60% exceeded the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) guideline of 0.123 mg/m3" (Lemus et all, 1998). While this sample size was only 53 homes, this suggests that other homes may have levels of formaldehyde that are higher than the safe amount.

During the Obama Administration, the U.S. government passed the Formaldehyde Standards for Composite Wood Products Act in 2010, which sets limits on how much formaldehyde home products can contain. The amount is .11 parts per million (ppm). This is higher than the amount in Europe (.07 ppm). California set the maximum to .05ppm (U.S. Congress, 2010) It is interesting that Europe, the US, and California all have different maximum ppm of formaldehyde. The health effects of formaldehyde is the same between regions, but the regulations are different. One year later in 2011, the US National Toxicology Program stated that formaldehyde is a known human carcinogen. Due to the concerns over formaldehyde, MDF is now available free of formaldehyde or with low levels of formaldehyde. However, some of the alternative glues may also pose health risks to humans and many of the formaldehyde resin replacements contain chemicals that have not been tested for human safety. Designers and architects should be aware of the health risks associated with conventional MDF and be cautious when specifying this type of material.

ENVIRONMENTAL CREDITS

Recycled Content (MR credit 4)	Awards 1 or 2 points for using products with recycled content that constitute at least 10% or 20%, based on cost, of the total value of project materials.
Regional Materials (MR credit 5)	Awards 1 or 2 points for using materials on a project that are extracted and manufactured within 500 miles that constitute at least 10% or 20%, based on cost, of the total value of project materials.
Environmental Quality (EQ credit 4.4)	Requires composite wood products used on project to demonstrate documented compliance with California Air Resources Board ATCM formaldehyde requirements for ultra-low-emitting formaldehyde (ULEE) resins or no-added-formaldehyde (NAF) resins.
Low-VOC Emitting Materials (G2.9)	Specifies architects to select low-VOC emitting materials
Pre-consumer Recycled Content (604.1(2))	Use recycled content products in major areas such as walls, floor, insulation and roofing.
FSC® Certification (606.2(3))	Wood or wood-based products available that are certified by Forest Stewardship Council™.
Other Certification (606.2(6))	Wood-based components certified in accordance to CPA ECC 4-11.
Low Formaldehyde/VOC Emissions (901.4(a))	In compliance with ANSI A208.1.
Low Formaldehyde/VOC Emissions (901.4(c))	In compliance with CPA ECC 4-11.
Low Formaldehyde/VOC Emissions (901.4(d))	Composite wood contains no urea formaldehyde.

Figure 4.5: Ultrastock MDF Environmental Credits
Source: Georgia Pacific

CERTIFICATIONS

ECC CERTIFICATION UltraStock MDF products produced in the Georgia-Pacific facility in Mt. Jewett, Pennsylvania, have been awarded the Composite Panel Association (CPA) Eco-Certified Composite (ECC) grademark which verifies compliance with the CPA 4-11 ECC Sustainability Standard, the California Air Resources Board (CARB) Airborne Toxic Control Measure (ATCM) 93120 and the EPA TSCA Title VI rule.

FSC® CERTIFICATION UltraStock MDF that is certified to conform to the requirements of Forest Stewardship Council® standards for FSC Mix Chain of Custody and Controlled Wood manufacturing is available by special order.

Figure 4.6: Ultrastock MR MDF Environmental Certifications
Source: Georgia Pacific

Georgia-Pacific

SAFETY DATA SHEET

1. Identification

Product identifier — **WOOD PRODUCTS (PMDI BONDED)**

Product list

Temstock Free, Temstock Free MR, Temstock MR,

UltraStock MDF produced with pMDI resin Shelving, UltraStock Free, UltraStock Free MR, Ultrastock HD

DryGuard® OSB Sturd-I-Floor, DryMax®, Web stock, FiberStrong® Rim Board

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FiberStrong HD ™ (Mill#s 531, 532, 530, 475),
Blue Ribbon® (Mill#s 531, 532, 530, 475),
Camouflage Panel Featuring Mossy Oak ® (Mill#s 531, 475),
Realtree Camouflage Panel ® (Mill#s 531, 475),
Thermostat® OSB Radiant Barrier Roof Sheathing (Mill# 531, 475),
ForceField™ air and water barrier panels (Mill#s 475, 500, 531)

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3. Composition/information on ingredients

Mixtures

Chemical name	Common name and synonyms	CAS number	%
WOOD/WOOD DUST		Not Assigned	80 - 100
METHYLENE BISPHENOL ISOCYANATE (MDI)		101-68-8	1 - 5
POLYMERIC MDI (pMDI)		9016-87-9	1 - 5
2,4'-DIPHENYL METHANE DIISOCYANATE		5873-54-1	0.1 - 1
Other components below reportable levels			0.5 - 1.5

The specific chemical identity and/or percentage of composition has been withheld as a trade secret.

Figure 4.7: MDF Safety Data Sheet
Source: Georgia Pacific

New Jersey Department of Health and Senior Services

HAZARDOUS SUBSTANCE FACT SHEET

Chronic Health Effects

The following chronic (long-term) health effects can occur at some time after exposure to **Methylene Bisphenyl Isocyanate** and can last for months or years:

Cancer Hazard

* While **Methylene Bisphenyl Isocyanate** has been tested, it is not classifiable as to its potential to cause cancer.

Reproductive Hazard

* According to the information presently available to the New Jersey Department of Health and Senior Services, **Methylene Bisphenyl Isocyanate** has not been tested for its ability to affect reproduction.

Other Long-Term Effects

* **Methylene Bisphenyl Isocyanate** may cause a skin allergy. If allergy develops, very low future exposure can cause itching and a skin rash.
* **Methylene Bisphenyl Isocyanate** may cause an asthma-like allergy. Future exposure can cause asthma attacks with shortness of breath, wheezing, cough, and/or chest tightness.
* Repeated allergic lung attacks may lead to permanent scarring of the lungs (pulmonary fibrosis), with reduced lung function.

Figure 4.8: Methylene Bisphenyl Isocyanate Hazardous Fact Sheet
Source: New Jersey Department of Health

EPA
United States
Environmental Protection
Agency

4,4'-Methylenediphenyl Diisocyanate (MDI)

101-68-8

Hazard Summary

The commercial form of 4,4'-methylenediphenyl diisocyanate (MDI) is used to produce polyurethane foams. Acute (short-term) inhalation of high concentrations of MDI may cause sensitization and asthma in humans. Acute dermal contact with MDI has induced dermatitis and eczema in workers. MDI has been observed to irritate the skin and eyes of rabbits. Chronic (long-term) inhalation exposure to MDI has been shown to cause asthma, dyspnea, and other respiratory impairments in workers. Respiratory effects have also been observed in animals. No adequate information is available on the reproductive, developmental, or carcinogenic effects of MDI in humans. EPA has classified MDI as a Group D, not classifiable as to human carcinogenicity.

4.3 Reproductive and developmental toxicity

The effects of PMDI on reproduction have not yet been investigated.

Figure 4.9: MDI Hazard Summary
Source: U.S. EPA

Because formaldehyde is a known carcinogen, it is being phased out of MDF and other similar wood products. One product by Georgia Pacific called Ultrastock MR MDF (see Figure 4.5) was given a variety of environmental credits for low formaldehyde emissions. However, the product does not contain any formaldehyde resins. Instead, methylene biphenyl isocyanate (MDI), polymeric MDI (pMDI), and diphenylmethane diisocyanate were used to bind the wood dust together (see Figure 4.6 for the Safety Sheet). Isocyanates were discussed earlier with spray foam insulation. According to the hazardous fact sheets (Figures 4.7 and 4.8) Methylene bisphenol isocyanate (MDI) has not been tested for reproductive health or cancer hazards. MDI and PMDI were correlated with respiratory issues, but no reproductive health studies are available. In summary, a product was given a variety of environmental health awards and certifications even though it contains chemicals that are harmful to human health and contains chemicals that have not been tested for safety. It is important that designers are cautious when specifying materials that are labeled as low emitting or eco-friendly. When one harmful material is replaced with another harmful material, human health is still in jeopardy. There is no benefit when one harmful chemical is replaced with another harmful chemical. A synthetic chemical resin may last longer than a natural one and it is difficult for designers and architecture to decide if the benefits outweigh the risks.

Carpet

An example of a building material that is harmful to humans and the environment is carpet. “Every year, about 5 billion pounds of carpeting go into landfills. That's 1 to 2 percent of the total U.S. landfill contribution, or 17 pounds of carpeting per person” (EPA, Waste 2016). There are different types of carpets and recent initiatives have been made to close the loop in the carpet lifecycle, but most carpet is still thrown in the landfill. Most carpets are derived from petroleum which requires vast amounts of resources to extract. Conventional carpet poses risks to human health for different reasons. First, most carpet backings contain high levels of volatile organic Compounds (VOCs) which are linked to human health risks. Second, carpet can trap other indoor contaminants. “Ventilation engineers like Douglas Galton were vehemently opposed to carpet, which they denounced as unhealthy dust catchers” (Rybczynski, 1986, 149). Modern vacuums may address the second concern with carpet, but the toxicity of the carpet assembly is still a health concern. A third concern with carpet is the stain free coating that is often desired in commercial application. California's Department of Toxic Substances Control (DTSC) released a draft report about possible regulation for class of chemicals used on carpets and rugs called polyfluoroalkyl substances (PFAS) (sometimes called PFCS). This chemical class is made from more than 3,000 chemicals and could affect the kidney, liver, immune system, and endocrine system. (CA DTSC, 2018) In addition to the risk posed by PFA's, they also contain high levels of VOCs. There are better alternatives to toxic carpet,s including ones made from natural materials like wool, hemp, cotton, jute, and natural latex using only natural dyes.

Vinyl

Vinyl is a term used to refer to a group of chemicals in the vinyl category. One of the most common chemicals in this group is polyvinyl chloride (PVC). PVC was first synthesized in the 1930s and by the 1960s it became widely used in a variety of products. "PVC is used to make a variety of plastic products including pipes, wire and cable coatings, and packaging materials. Other uses include furniture and automobile upholstery, wall coverings, housewares, and automotive parts" (U.S. CDC, 1997). Figure 4.9 shows the variety of vinyl floors that were colorful and easy to maintain. Vinyl became even more popular during the 1960s because of its hygienic appeal. It could easily be cleaned and did not harbor insects or mold. Similar to the way that asphalt roads seem cleaner than dirt roads, vinyl floors seemed to be cleaner than natural wood floors.

Figure 4.10: Vinyl Tile Advertisement, 1953-56
Source: KenFlex Flooring

Today, vinyl is the most common siding material in new construction and one of the most popular materials for interior floors. Synthetic materials are often manufactured to imitate natural materials and vinyl hardwood imitation flooring is often advertised as a luxury material and sometimes called “vinyl hardwood”. While vinyl may have some benefits, it is harmful to human health. The U.S. Department of Health and Human Services determined vinyl chloride as a known carcinogen. PVC pipes are used to carry almost all drinking water to commercial and residential buildings, but there is no information about the amount of vinyl chloride released from the pipes into the water. Long term exposure to vinyl is problematic and people who work in vinyl production facilities are at risk. “Because vinyl chloride usually exists in a gaseous state, you are most likely to be exposed to it by breathing” (U.S. CDC, 1997). We do not often think about breathing in chemicals from the floor, but flooring selection will impact indoor air and the indoor environment. Figure 4.10 shows that from distance, vinyl flooring can look very similar to hardwood flooring.

Figure 4.11: “Luxury” Vinyl Flooring
Source: Home Depot

Paint

Paint is the final layer of the interior. Historically, paints were made from natural materials, but most paints today are made from a blend of synthetic materials. Linseed oil was a common ingredient in paint, however the shortage of linseed oil during WWII led to the development of synthetic and artificial resins. Today, most paints contain volatile organic compounds (VOCs). "Adverse health effects associated with moderate and high VOC concentrations include eye and respiratory irritation, irritability, inability to concentrate, and sleepiness" (Bauman, 2000). Category 5 of building products (paints, sealants, glues…) are installed on site. Even though they are low mass and do not contribute significant to landfill waste, however, "category 5 products are virtually impossible to recycle, and in many cases are sources of contamination for other categories of products, making their recycling more difficult" (Kibert et al, 2002, pg. 25).

Figure 4.12: Synthetic Paints
Source: CDC

Paint prevents the recyclability of other building materials. For example, painted wood cannot be recycled in the same way as unpainted wood. Paints, sealants, and adhesives prevent or make difficult the process of recycling because it is nearly impossible to separate the paint or glue from a product. The sealants and adhesives that prevent the recyclability of building materials often contain chemicals that are harmful to human health. Choosing mechanical fasteners over chemicals fasteners will improve indoor air while allowing materials to be reused in the future. Paint used to be made with lead, but in 1978 the government regulated lead in paint. This example shows how government regulations impact human health. Paint manufacturers removed lead from paint and were still able to make a profit with lead free paint. It is important to distinguish between the different types of paint. Low VOC paint may be advertised as eco-friendly, but something that is less toxic is still toxic. Even zero VOC paint will still off gas (as everything does) but is a better alternative than low VOC or conventional paint.

Building Materials Summary

Sustainability goes beyond the selection of building materials and a building cannot be truly sustainable if it only addresses one aspect of sustainability. Materials are important because we spend so much time indoors and are exposed to new synthetic building materials. “The introduction of tens of thousands of synthetic chemicals, many of them hazardous, into the global environment is another factor that is causing documented illness and disturbances to the reproductive system of animals, including human, throughout the world" (Kilbert et al, 2002, pg. 30). Any initiative to protect the environment should also protect human health. Human health has been in competition with environmental health for decades, but ultimately the sustainability of the earth and the sustainability of humans should share goals. We often think of ourselves as separate from our environment, when we are all part of the same system. While no building materials is perfect, architects and designers can directly impact the indoor environment through the materials they specify. New and popular building materials like spray foam insulation, foam with flame retardants, MDF, carpet, vinyl, and paint are ubiquitous and pose risks to human health.

Chapter 5: History, Competition, Regulation, of Indoor Air

"Any damn fool can build homes. What counts is how many you can sell for how little."

- William Levitt, c. 1950

Unintended Consequences

Architecture originally served as shelter from the elements, but architecture can also harm occupants and pose risks to human health. Building occupant health is not protected by any U.S. laws or regulations. Poor indoor air quality can be hard to detect and health issues may be difficult to diagnose, but in certain cases there is a direct identifiable link between the building materials and occupant health. After Hurricane Katrina in 2005, thousands of Americans along the Gulf Coast of Florida and Louisiana were displaced. The Federal Emergency Management Agency (FEMA) quickly responded to the natural disaster by providing mobile homes to the displaced residents. While residents were thankful to receive shelter, many began to experience unprecedented health issues. Trailer occupants complained of headaches, nosebleeds, and respiratory issues. After multiple complaints, the CDC tested formaldehyde levels in the trailers and found, "formaldehyde levels in closed trailers averaged 1.04 parts per million (ppm), with some measurements exceeding 3.50 ppm" (CDC, 2007). This created problems for the both the occupants living in the trailers and the people testing the formaldehyde levels. OSHA workers were required to wear respiratory equipment when entering the trailers because the formaldehyde levels exceeded permissible exposure limits. OSHA formaldehyde limits are:

- .75 ppm: Permissible exposure limit (PEL)
- .50 ppm: Action Level (AL)
- 2.0 ppm: Short Term Exposure Limit (STEL)

While the amounts may seem small, even just 0.1pm can cause respiratory issues. It is estimated that 114,000 individuals lived in the trailers in 2008 (Brunker, 2008). While the trailers were intended for short term occupation, some people were still living in the trailers over a decade later. Some of the trailers "had formaldehyde levels at 75 times the recommended threshold for workplace safety" (Smith, 2015). Ironically, OSHA workers were required to wear respiratory equipment to enter a place where people live without any sort of protective equipment. Figure 5.1: Sticker in FEMA trailer reads "NOT TO BE USED FOR HOUSING"

Figure 5.1: FEMA Trailer
Source: Nick Shaprio

Over the years, formaldehyde levels have been dropping but they are still above the safety limit. “What exactly did this mean? It’s hard to say, because no one has systematically studied how the toxic trailers might have actually harmed their residents” (Smith, 2015). This example shows the challenges of protecting human health in the indoor environment. While these FEMA trailers were particularly problematic, other trailers may also have dangerously high levels of formaldehyde. In the U.S, about 6% of Americans permanently live in mobile homes.

Single Family Homes

The Gulf Coast FEMA mobile homes show that indoor air quality directly impacts occupant health. While there over 20 million Americans living in mobile homes, most Americans (about 260 million) live-in single-family homes. According to the National Association of Realtors 2011 Community Preference Survey, “living in a single-family, detached home is important to most Americans. Eight in ten (80%) would prefer to live in single-family, detached houses over other types of housing such as townhouses, condominiums, or apartments” (NAR, 2011). Single family homes are popular in part because it is part of the American dream and ownership is appealing. There are different ways to build and buy a single-family home. The following case studies analyze custom built single-family homes. Custom homes allow the client to make materials choices and to be involved in the construction process. The appeal of home ownership is a key reason why most Americans prefer to own a single-family home. Custom built homes by Lake

Flato Architects, *Furman & Keil Architects, and* by Tornbjerg Design + Laura Britt Design will be analyzed based on building materials.

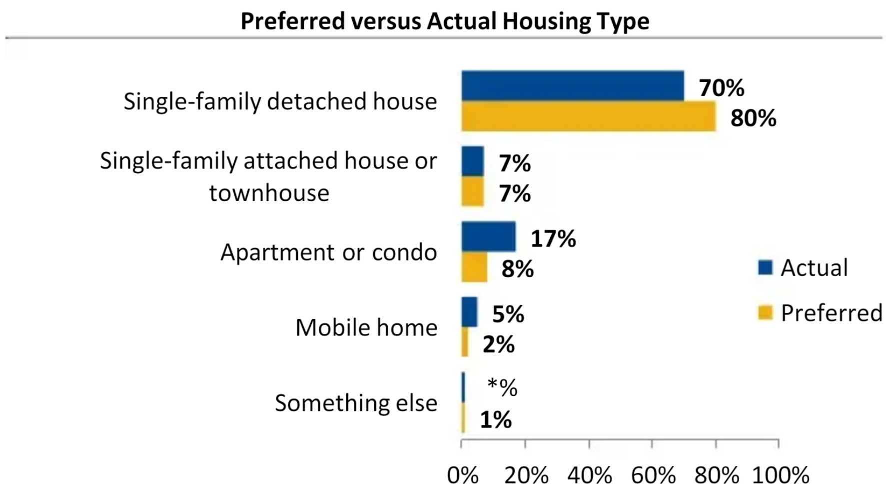

Figure 5.2: Preferred Versus Actual Housing Types, 2011
Source: National Association of Realtors

Lake Flato Architects

While indoor air quality continues to pose risks to human health, there are many examples of buildings that have successfully addressed indoor air quality. A custom home by Lake Flato Architects in Leon Springs, Texas addresses both energy efficiency and indoor air quality. The clients were directly involved in the design process. This home was finished in 2010 and features a variety of natural and local materials including wood flooring, cabinets, and doors. One strategy to reduce chemical contamination was the use of water-based sealants on the wood floors because conventional oil-based sealants contribute to indoor air contamination. The clients were interested in both energy efficiency and indoor air quality. This home shows that these two competing logics can both be addressed without compromise. One of the main reasons this home addresses the indoor environment is because the clients desired a healthy home before construction began.

Figure 5.3: Leon Springs Home Kitchen
Source: Lake Flato Architects

Furman & Keil Architects

Another home that addresses indoor air is a custom home in Westlake, Texas. The home by Furman & Keil Architects features white oak wood flooring throughout the interior to create a seamless transition between spaces. The stainless-steel kitchen countertop is antimicrobial and nontoxic. Flame retardants and stain resistant chemicals were avoided in the furniture and fabrics. The garage is not attached to the main house to avoid car emissions entering the home. This healthy home was driven by the clients, who were both educated about building materials. Architect Philip Keil estimated that the home cost about 10% more to build than a conventional home.

Figure 5.4: Custom Westlake Home Kitchen
Source: Furman + Keil Architects

Gradients of Green

A third example of a home that addressed indoor air quality was designed by Tornbjerg Design and Laura Britt Design in Austin, Texas that was completed in 2015. Britt calls the home "Gradients of Green" because there are no perfect materials, but there are more appropriate materials. Zero VOC paints, zero VOC furniture, and zero VOC wood flooring adhesives help reduce chemical contamination. Natural oak floors were used throughout the home and the kitchen cabinets are also made from wood. The air quality is constantly monitored. Electronic equipment, which often contains flame retardants, was strategically placed in a separate closet with direct ventilation to the outdoors. The master closet also features a direct vent to outdoors. Like the two previous homes, the desire for human health was driven by the clients.

Figure 5.5: “Gradients of Green” Home Kitchen
Source: Laura Britt Design

Popularity of Production Homes

The examples of custom homes show that it is possible to build a healthy home. Despite the growing awareness of indoor air quality, most Americans live in non-custom production homes that do not address human health. Production homes are more common than custom homes because they cost less than half the price to build. Out of all the single-family homes in the United States, 22% are considered custom (NAHB, 2016). This percentage includes built to sell/ speculation homes. Of the 22% of custom homes, 68% are spec homes. Only 7% of single-family homes in the United States are non-spec custom homes (Contractor Built, Owner Built, Built for Rent). Most Americans have no impact on the material selection of their home.

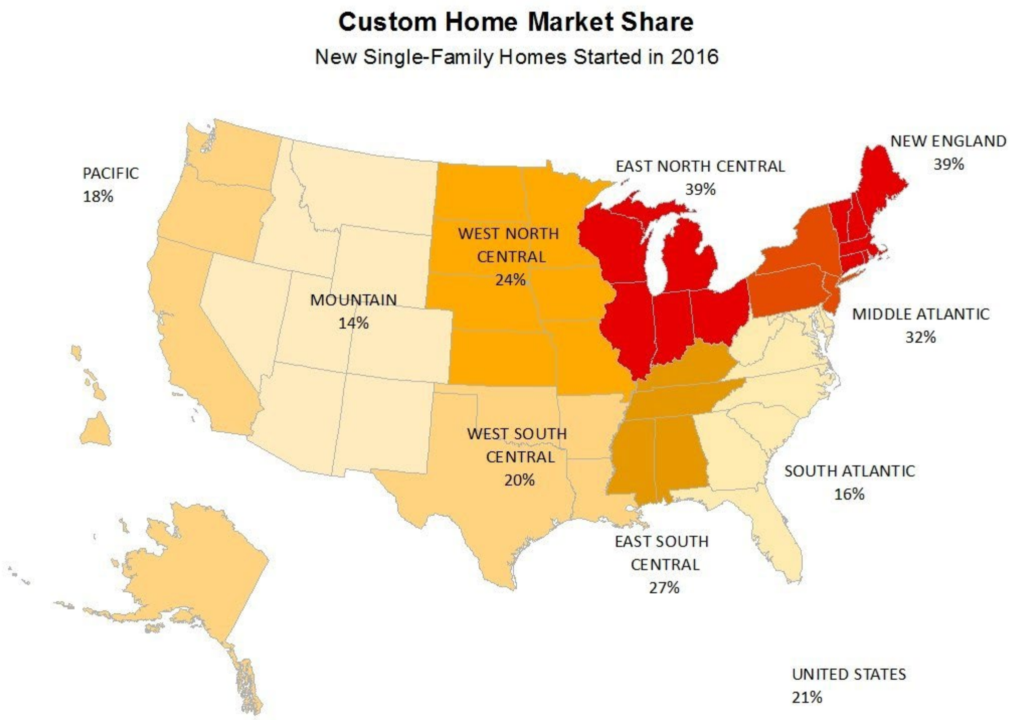

Figure 5.6: Custom Home Market Share
Source: 2016 Survey of Construction (SOC) NAHB

Before the Establishment of the FHA in 1934, most Americans rented a place to live, or if they had funds, they would purchase an already built home or build a house themselves. Mortgages allowed Americans to avoid paying the full amount at once and the establishment of the FHA gave rise to production homes. In the US, roughly 1 million homes were built each from 2005-2017 (US Census, 2018). Single-family housing starts in July were at a rate of 876,000 (US Census, 2019). Texas leads the nation with about

15% of the total of homes constructed. The distribution of building permits in the US between 2017-2018 shows the preference for single family homes. “840,000 single-family homes completed in 2018. (US Census, 2018). With about a million new homes built each year, there are opportunities to address indoor air quality.

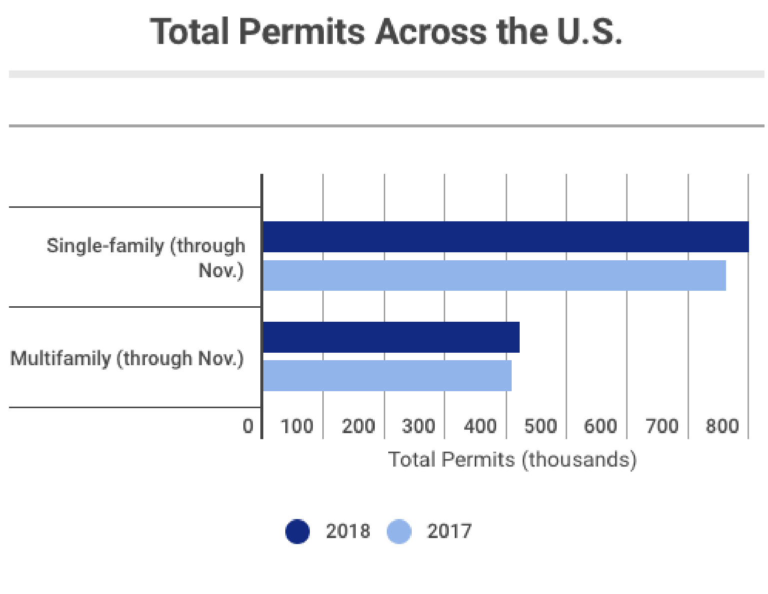

Figure 5.7: Permits for Single Family Homes
Source: U.S. Department of Housing and Urban Development

Production Home Case Studies

Because single family homes are most popular, they will be analyzed further through a series of case studies. Indoor air quality will be assessed based on the material selection and ventilation systems. Five different US real estate development companies will be analyzed: D.R. Horton. KB Homes, David Weekley Homes, Fulton Homes, and storybuilt (formerly PSW). Despite being located in various regions of the US, production homes have a similar look and master plan. While these homes vary in price depending on location and construction, they are all beyond the average annual income. According to the US Census Bureau, the median household income in 2018 was $63,179.

Figure 5.8:	Production Homes in Newport Coast, California
Source: Orange County Register

D.R. Horton

D.R. Horton is America's largest home builder by volume since 2002. They operate in over half of the states in the U.S. and built around 45,000 homes in 2017 and have built over 715,000 homes in total. The average selling price is about $300,000. D.R. Horton had a revenue of 14 billion dollars in 2017 and is on the Fortune 500 list. D.R. Horton was first established in Fort Worth, Texas in 1978 and they are currently headquartered in Arlington, Texas. Each home comes with a complete homeowner's manual that can help homeowners properly maintain their home. Some common features of D.R. Horton homes are vinyl flooring, oil-based paints and enamels, laminate countertops, latex and silicone caulking, and blown in insulation.

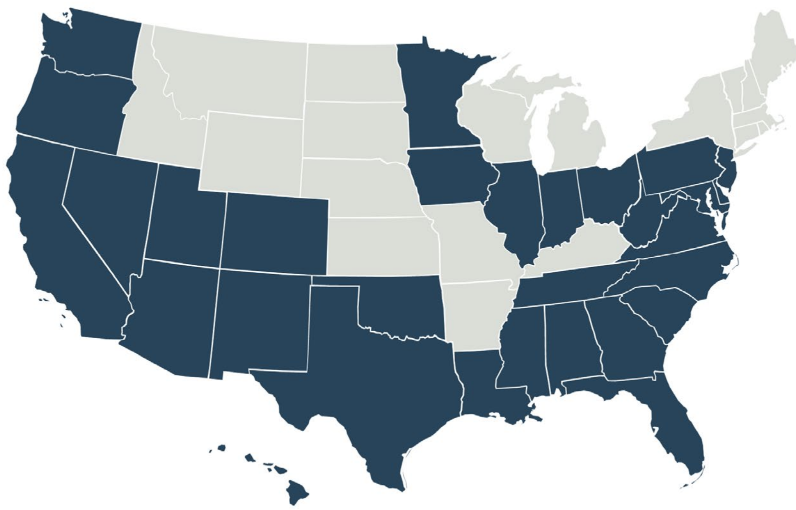

Figure 5.9: D.R. Horton Operates in Blue States
Source: D.R. Horton

The owner's manual for homes in Houston gives extensive information about the care and maintenance of the home. Some of the suggestions they make regarding maintenance can also improve the indoor environment. "The most important thing you can do to protect your carpet is to vacuum it frequently" (D.R. Horton Houston Manual, 34) Because SVOCs attach to dust particles, vacuuming is important. "Scented candles or oil lamps produces ash that gets distributed throughout your home by the central A/C

Heating system" (D.R. Horton Houston Manual) Indoor combustion from smoking contributed to poor air quality and the manual also shows that the ash from smoking can be redistributed to the rest of the home. The manual also states, "Burning a fire should be looked upon as a luxury, adding much to the atmosphere but just a little heat to the home. About 10 percent of the heat produced by a fire is radiated into the home. As a fire burns, it draws warm air from the house for combustion." While the manual gives relevant information and confirms the fact that a healthy home requires both conscious behaviors and specific materials." A healthy home requires both materials and behavior.

KB Home

This real estate developer was founded in Detroit, Michigan in 1957 and is now headquartered in Los Angeles with projects in Arizona, California, Colorado, Florida, Nevada, North Carolina, Texas, and Washington. The average KB home is sold for $400,000 and KB homes has built over 500,000 homes. Some homes are energy efficient and according to KB Home, homeowners can save up to $2000 annually on utility bills with a KB home. KB Homes also partnered with the EPA to offer homes through the Indoor airPLUS certification program in 2015. In order for a home to be considered for certification, energy efficiency must first be established. The certification is mostly about the ventilation system and also requires that materials are low emitting. According to a KB homes representative, all new KB homes are indoor air plus certified. KB Home has a variety of building locations and prices, but the materials are somewhat similar between locations. For example, Figure 5.10 shows an image of a home in Irvine, California for 1,200,000. The home price is driven by its location and not the quality of the building materials.

Figure 5.10: KB Home Concept in Irvine, California
Source: KB Home

David Weekely Homes

David Weekley Homes was founded in Houston, Texas in 1976 and they are still located in the same place. They build homes in 22 cities across the United States and Canada: Atlanta, Austin, Charleston, Charlotte, College Station, Colorado Springs, Dallas/Ft. Worth, Denver, Houston, Indianapolis, Jacksonville, Nashville, Minneapolis/St. Paul, Orlando, Phoenix, Portland, Raleigh/ Durham/ Chapel Hill, Salt Lake City, San Antonio, Sarasota, Tampa, Vancouver. They have built over 90,000 homes and the average selling price is $400,000. Their homes are advertised as energy efficient and homeowners can save about $2,000 in utility fees compared to a conventional home according to their website. Their website states,

> "Indoor air quality is an essential component of every David Weekley EnergySaver home. Our construction methods create a tighter environment with reduced drafts and controlled fresh air ventilation. You might be surprised to learn that the homeowner is often the biggest contributor to poor indoor air quality. The EPA says concentrations of toxic pollutants can be up to 100 times greater inside a home than outside – even in the smoggiest cities. Where does all this indoor pollution come from? Litter boxes, trash cans, cooking, smoking, even candles, which is why you'll breathe easier with our fresh air ventilation system." (David Weekley Website)

While it is true that human behavior plays a role in IAQ, the off gassing of materials also impacts IAQ. They forgot to mention that indoor building materials are significant. Creating a tighter envelope keeps dust and pollutants out, but it also traps unwanted chemical contamination inside the home. Energy efficiency and human health are both aspects of sustainability but in this case, human health is being compromised for energy efficiency. Common material used in David Weekley Homes are merv 11 air filters and blown in cellulose insulation.

Fulton Homes

Fulton Homes is Arizona's largest privately-owned home builder. They were established in Tempe, Arizona in 1975 and are headquartered in Tempe. They build homes in different areas of Arizona including the Phoenix suburbs and have built over 40,000 homes with an average price of $435,000. Fulton began using the EPA Indoor airPLUS certification program in 2014 and has built over 650 airPLUS certified homes. Since airPLUS can only be added to Energy Star certified homes, these homes address both indoor air quality and energy efficiency. Indoor airPLUS homes use no-VOC or low-VOC paints and sealants, and low-formaldehyde manufactured wood products. Fulton Homes has their own designer where a buyer can customize some of the finishes for their new home. They can choose or upgrade: paint, cabinets, flooring, appliances, fixtures, doors, lighting, Fans, insulation, and HVAC. One flooring option listed was luxury vinyl tile and their standard insulation was spray cellulose.

EPA Indoor airPLUS 2018 Indoor airPLUS **Leader of the Year**

Figure 5.11: 2018 Indoor airPLUS Leadership Award
Source: EPA

Storybuilt (formerly PSW)

Storybuilt (formerly PSW) is a real estate developer with about 700 homes built and an average selling price of $550,000. Thy were first established in Phoenix, Arizona in 2001 but are now headquartered in Austin, Teas. Storybuilt has built homes in Austin, Dallas, San Antonio, Denver, and Seattle. They build single family homes, townhomes, and condos in fast growing cities. They were first established in 2001 and added an in-house architect team in 2011. Austin is a growing city with growing demands for energy. Many of the homes by storybuilt use spray foam insulation to reduce operational energy in each home. According to their website, common materials for flooring are stained concrete and engineered wood. They also use wood overlay cabinets, low VOC paint and spray foam insulation.

Healthy Homes are Client Driven

During the construction process, materials are specified at various stages. For a custom home, the client may choose materials before construction has begun. In most production homes, the future owner may or may not be able to make any selections. If they are able to make a selection, it is at the very end of construction as shown in Figure 5.12. The owner may be able to pick some of the finish, like the kitchen countertop, flooring, or paint color. Based on the architectural case studies, a healthy indoor environmental is not accidental but rather the result of decisions made early in the design process. Health environments are client driven. Most Americans live in non-custom production homes and many of these homes are built with new synthetic products. Figure 5.13 shows how production homes became popular in the United States. Even though production homes are built in different climates and geographies, many feature similar materials and were built using similar techniques. A $2,000,000 production home in California and a $300,000 production home in Arizona have very similar construction materials. Energy efficiency is addressed and is becoming more standard in production homes while indoor air quality is beginning to be addressed. However, even if a home is indoor airPLUS certified, unhealthy building materials may still be present.

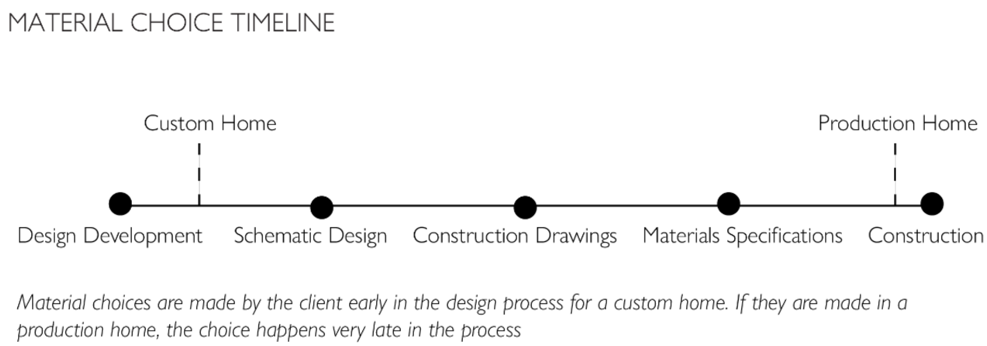

Figure 5.12: Material Choice Timeline

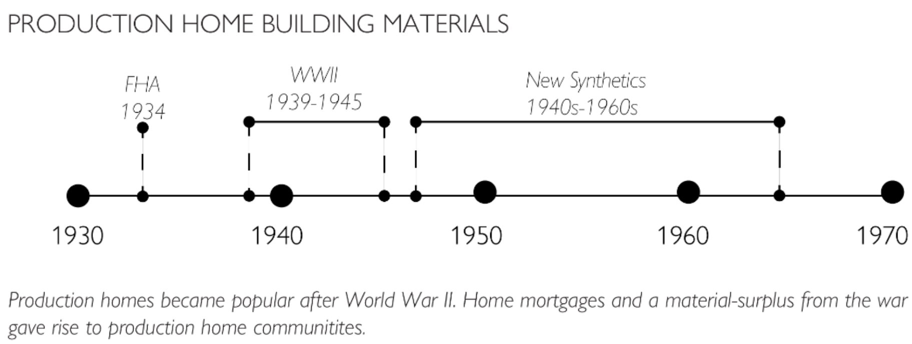

Figure 5.13: Production Homes and Building Materials

Chapter 6: Conclusion

"It turns out that interior designers have a lot more influence on our health than our doctors"

– Jeffrey Siegal, 2013

Importance of the Indoors

Indoor air scientist Jeffrey Siegal stated that interior designers influence our health more than our doctors. While this quote makes a bold and controversial statement, there is merit to Siegal's statement. Because indoor air is a top threat to human health and we spend most of our lives indoors, the material and design decisions made by both designers and architects directly impact human health. There is no available data on performance and productivity in residential architecture, but two different studies link higher performance in "green" work environments compared to conventional work environments. Similar results could be assumed for residential environments. A variety of different professionals make decisions throughout the design process that impact the quality of the indoor environment. During westward expansion, building development fit into a larger narrative of American progress. The outdoors was described as uncivilized, unpredictable, and dangerous. However, this narrative has flipped and now the indoors is considered dangerous and problematic to human health. There are a variety of decisions made by designers and building occupants that impact the quality of the indoor environment and human health.

History

Starting in the 18th century, innovations in heating and lighting technology led to a combustion free interior. Electricity replaced the open flame used for heating and cooking and combustion was relocated to a power plant. The post WWII chemical revolution led to ubiquitous use of new building products with unknown health effects. Suburban sprawl furthered increased the dependence on the car leading to the attached garage. This worsened IAQ because when the garage is attached, fumes and gases can make their way from the garage into the house. The establishment of the FHA and availability of mortgages facilitated mass home ownership. Production homes were made possible by both the demand for home ownership after the war and new affordable synthetic materials. After WWII, the U.S. government subsidized the plastic industry and new plastic products were desired for their hygienic appeal. New synthetic building materials performed well, but as air conditioning became popular, more houses were airtight and synthetic contaminants became trapped indoors. During the 1973 energy crisis, ventilation rates in buildings decreased to reduce energy consumption. In 1984 The World Health Organization (WHO) coined the term sick building syndrome (SBS) and later building related illness (BRI). Unhealthy indoor environments can lead to acute and long-term health issues.

Outdoor air is federally regulated by the U.S. government through the Environmental Protection Agency (EPA). However, we spend most of our lives indoors at home and there are no federal regulations for residential indoor environments. There are regulations in certain states for indoor work environments and most states have banned smoking in public indoor spaces. Since the 1990s, a variety of voluntary “green” standards for buildings and building products have become available for designers to use, but because there are so many standards, it is difficult to choose which one is most appropriate.

Building materials impact human health. The significance of materials is amplified because we spend so much time indoors. Custom built homes have potential to be healthy, but most Americans live in homes built by developers using conventional materials. The desire for low maintenance and high-performance materials has led to a preference for synthetic building products. Natural products are often more expensive upfront and some require more maintenance than their synthetic counterpart. For example, there is no need to use special cleaning products or sand and polish a vinyl floor. Many Americans are not aware of any health risks associated with certain synthetic building products, so most choose the least expensive product. Safety and health information is often difficult to obtain and safety data sheets (SDS) are not always available.

Professional Challenges

It is difficult for designers to determine if the benefits of a material outweigh the risks because designers are typically not trained in toxicology, chemistry, or medicine. It is also difficult to understand safety data sheets without an understanding of chemicals and their health effects. While safety data sheets are available for most products, they can be difficult to find. Manufacturers are not required to list all the ingredients in a product, making it more difficult to determine if a product is appropriate. In general, it is better to only specify materials with a full ingredients list on the SDS.

At the 12th International Conference on Indoor Air Quality and Climate in 2011, the conference preceding report contained over 3,000 pages of indoor air science and the table of contents was over 100 pages. This shows that there is data available, but designers are not trained to interpret scientific data. Engineers may have exceptional knowledge of indoor air quality and indoor environmental quality, but most decisions are made by designers and architects. The data and research regarding IAQ and IEQ can be used to impact design decisions, but it is difficult for designers to decipher the data.

Regrettable Substitutions

When a product is deemed unsafe, alternative products make their way into the building materials market. For example, after formaldehyde was declared a carcinogen by the CDC, formaldehyde free products became available. Firemaster® 550 replaced PBDEs, the main component in flame retardant chemicals, but both of these chemicals are in the same class and have similar health effects. Replacing one known harmful chemical with another known harmful chemical does nothing to improve IEQ. One brand of formaldehyde free MDF used synthetics resins that were not tested for human safety. While the product was formaldehyde free, it is unknown if the resins in the formaldehyde free MDF are safer than the resins in the standard MDF. There is a lack of research on alternatives for these building products that are often advertised as being “green” or eco-friendly.

Human Behavior

A healthy indoor environment is the result of decisions made by designers, builders, and occupants. Even if you live in a home with conventional synthetic materials, everyday decisions can impact IEQ. Figure 6.1 shows the four quadrants of homes and behaviors. At one corner is a home with healthy materials with an occupant practicing good IAQ behavior which is the best-case scenario. The middle scenarios are a healthy home with poor occupant decisions and an unhealthy home with good occupant IAQ decisions. At the other corner is a home with unhealthy materials and an occupant who makes poor IAQ choices, the worst-case scenario. A conventional home with a conscious occupant could be just as healthy as a healthy home with poor occupant decisions.

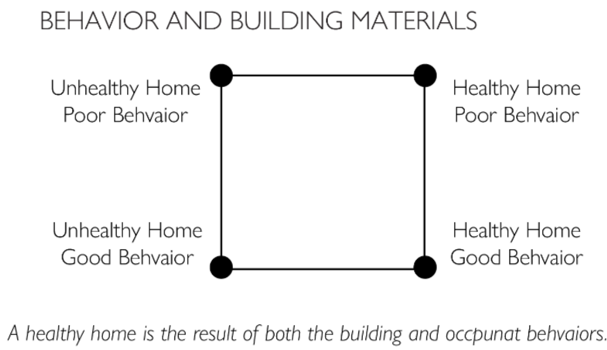

Figure 6.1: Healthy Home Scale

Most Americans do not have control over the building materials in their home. However, there are a variety of decisions that one can make to improve their indoor environment as shown in Figure 6.2. Taking your shoes off upon entering a home will reduce the chance of contamination. Cleaning your house regularly can help remove dust, pollutants, and airborne debris. Because semi volatile organic compounds (SVOCs) can leach into the air and attach to dust particles where they can be inhaled, keeping the home dust free is important for human health indoors. Vacuuming regularly can help reduce contamination from dust and using an air filter can also remove indoor pollutants and debris from the air. Making sure to use the range fan while cooking will help to filter the air. Conscious cooking is important, and it is best to cook red meat outdoors. Everything that the occupant brings into the home will impact IEQ including furniture, cleaning products, and electronics. When exposed to oxygen, food rots and releases methane into the air. It is best to avoid putting food in the trash, but rather compost in the freezer or outdoors to avoid methane in the home. Cigarette smoke, candle smoke, incense, and smoke from burning food should all be avoided for maximum IEQ. A combination of all the strategies in Figure 6.2 will improve human health in the indoor environment.

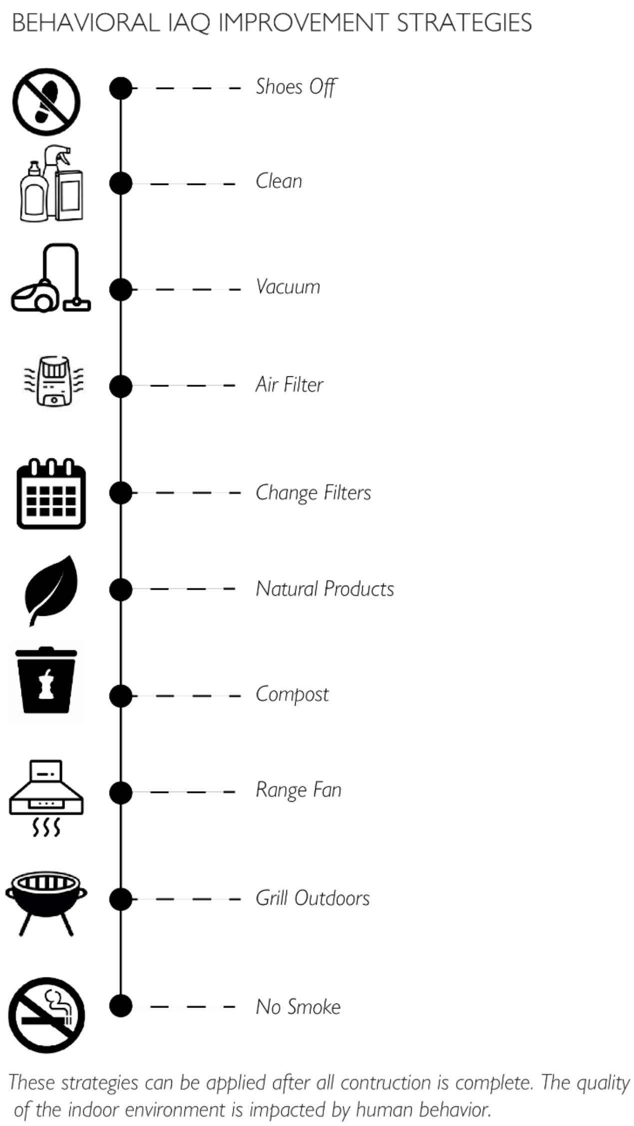

Figure 6.2: Behavioral IAQ Improvement Strategies

Final Remarks

Energy savings can be calculated in kilowatts and dollars, but it is difficult to calculate healthcare costs associated with poor IEQ. It is even more challenging to assign a monetary value to quality of life and wellbeing. Typically, "green" construction can cost more than conventional construction, but it has the potential to save occupants from future healthcare costs. Because the health effects of many building products are unknown, it is best not to specify those materials. A material should only be it specified if it does not cause significant harm to building occupants. It would be beneficial if building products were required to be proven safe before being available for purchase, but it is the opposite and a product must be proven harmful before being regulated. It is important to intentionally decide which material is most appropriate. It is also important to understand how a material is deemed appropriate and which metrics are used to measure appropriateness. A positive remark is that human health and IEQ are being considered more, even if it is secondary to energy efficiency. What is valued in architecture and design can be shown by the winners of architectural awards and competitions. While aesthetics and performance are significant factors, energy efficiency is a common criteria and human health is a new emerging topic. Given that poor indoor air quality is a top threat to human health, and we spend most of our lives indoors, the best things we can do is to spend more time outside.

Acronym Glossary

ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers
ATSDR: Agency for Toxic Substances and Disease Registry
BRI: Building Related Illness
CDC: Center for Disease Control
CLEE: Chronic Low-Level Exposure
DOE: U.S. Department of Energy
DTSC: Department of Toxic Substance Control
EPA: Environmental Protection Agency
EWG: Environmental Working Group
FEMA: Federal Emergency Management Agency
FHA: Federal Housing Administration
FRs: Flame Retardants
HUD: U.S. Department of Housing and Urban Development
HVAC: Heating, Ventilation, and Air Conditioning
IAQ: Indoor Air Quality
IEQ: Indoor Environment Quality
LBC: Living Building Challenge
LEED: Leadership in Energy and Environmental Design
MDF: Medium Density Fiberboard
MDI: Methylene Bisphenol Isocyanate
pMDI: Polymetric Methylene Bisphenol Isocyanate (Diphenyl Methane Diisocyanate)
MSDS: Materials Safety Data Sheet
MSC: Multiple Chemical Sensitivity
NAHB: National Association of Home Builders
NAR: National Association of Realtors
NHAHPS: National Human Activities Pattern Survey
OSHA: Occupational Safety and Health Administration
PBDE: Polybrominated Diphenyl Ethers
PFAS: Perfluoroalkyl Substances
PFCS: Perfluoroalkyl Compounds
PPB: Parts Per Billion
PPM: Parts Per Million
SBS: Sick Building Syndrome
SFI Spray Foam Insulation
SPF: Spray Polyurethane Foam
VOC: Volatile Organic Compounds
  SVOC: Semi-Volatile Organic Compounds
  TVOC: Total Volatile Organic Compounds
WHO: World Health Organization

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